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Industry 4.0: Trends in Management of Intelligent Manufacturing Systems

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Preface

The aim of the publication is to provide the most comprehensive and effective exchange of information on current developments and trends in the management of manufacturing systems and Industry 4.0.

The presented publication is a collection of latest research projects that were presented at the International Conference on Management of Manufacturing Systems (MMS 2017).

Our ambition was to establish channels of communication and disseminate knowledge among professionals working in manufacturing and related institutions. The event took place in Starý Smokovec, Slovakia, during November 22–24, 2017, and was endorsed by the European Alliance for Innovation, a leading community-based organisation devoted to the advancement of innovation in the field of ICT, and Faculty of Manufacturing Technologies with a seat in Prešov of Technical University of Košice.

This publication encompasses a total of 12 selected research articles with world-wide contributors. Among the project findings featured in this publication are those written by the conference keynote speakers, e.g. Dr.h.c. mult. Prof. Ing. Juraj Sinay, DrSc., the Head of the Department of Safety and Quality in Mechanical Engineering at the Technical University in Košice and the President of Automotive Industry Association of the Slovak Republic, and Prof. Dr. Dragan Perakovic, the Head of Department for Information and Communication Traffic and Head of Chair of Information Communication Systems and Services Management at the University of Zagreb. Next, at the conference presented highly acclaimed scholar Assoc. Prof. Dr. Oldřich Kodym from College of Logistics, Czech Republic, and Assoc. Prof. Dr. Vitalii Ivanov from Sumy State University.

In the light of the latest knowledge and findings from scientific projects, the authors present actual R&D trends in the given field. This issue not only defines the state of the art in the field, but it additionally explores related topics for future research. Moreover, we would like to thank the audience members who actively interacted in the discussion on the topics mentioned above.

Additionally, I would like to express my appreciation to Assoc. Prof. Dr. Michal Balog, Head of Department of Industrial Engineering and Informatics at the Faculty of Manufacturing Technologies with a seat in Prešov (TUKE) and Chair of the MMS 2017 Conference and all participants and authors of the conference.

Prešov, Slovakia Lucia Knapčíková

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I would like to thank all authors and reviewers. Many thanks to the Dean of Faculty of Manufacturing Technologies with a seat in Prešov of Technical University of Košice, to Dr. h. c. Prof. Dr. Jozef Zajac, to the Head of the Department of Industrial Engineering and Informatics, to Assoc. Prof. Dr. Michal Balog and to my colleague Dr. Jozef Husár.

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Chapter 1
Experimental Analysis of Properties and Possibilities of Application RFID Tags in Real Conditions

Michal Balog, Monika Trojanová, and Peter Balog

1.1 Introduction

The Fourth Industrial Revolution (Industry 4.0) has a number of distinctive features, depending on how a particular firm or institution decides to proceed. Based on the widely expanded version, it is the current trend in automation and high-quality information flows in production technologies using cyber-physical environment. The Fourth Industrial Revolution is characterized by the digitization of the manufacturing sector, typical of the surge in data volume, computing power, and connectivity (especially in new low-power networks). High-performance information technology provides new alternatives to analytics and business intelligence, unusual collaboration between people and machines, such as touch interfaces and the like. In Fig. 1.1 is a time axis of development from Industry 1.0 to Industry 4.0 [1, 2].

Research and development of intelligent products are intense and are capable of actively communicating with their users, for example, reporting their technical status, their position, state of the art, etc.

In 2013, one of the Hanover fairs was that in the interconnected world of Industry 4.0 intelligent factories will be part of the so-called Smart Infrastructure and the Internet of Things Network. Vertical and horizontal process integration can achieve an absolute new level in the broader engagement of smart products, where intelligent

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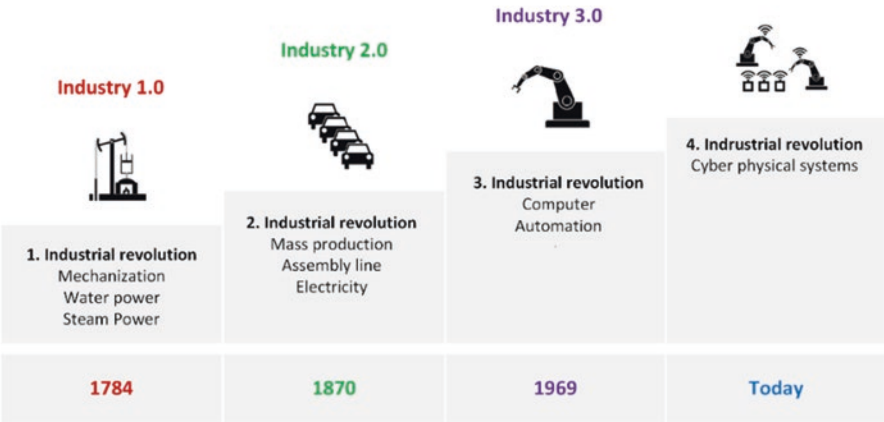

Fig. 1.1 Time axis of development from Industry 1.0 to Industry 4.0

manufacturing will enable people, material, and machine to interact with each other in a way similar to social networking. Smart products will be able to contribute to improving the quality of the production process, which will then be smoother, more efficient, and more reliable [2].

A highly intelligent environment will also have to meet all the components of the information systems, which in addition to their ability to work efficiently with enormous amounts of data, will also need to be functional in the full range of associated and necessary environmental influences such as pressure, humidity, temperature, vibration, and magnetism. The experiments carried out at the Department of Industrial Engineering and Informatics of Faculty of manufacturing technologies with a seat in Prešov, on selected RFID tags have shown that often the declared parameters at temperature do not correspond to realities and other than vibration, manufacturers do not even mention. Specific applications for the fourth industrial revolution, however, are mining operations, blast furnaces, but also rail transport, where all the parameters mentioned such as temperature, humidity, magnetism, and vibrations exist in negligible values [3].

1.2 RFID: Technology of Identification with Perspective

Radio-frequency identification is technology of an automatic identification in which the data is stored in a digital form in the so-called RFID tags (labels, chips) from which they can then be loaded and rewritten in a simple way using radio waves. The technology is relatively simple, it has its undisputed advantages over other identification technologies, and it will gradually replace, for example barcodes. The RFID tag is the information carrier which may be in the form of a label or in a closed form of different shapes, sizes, and materials. For reading and writing of data to the RFID

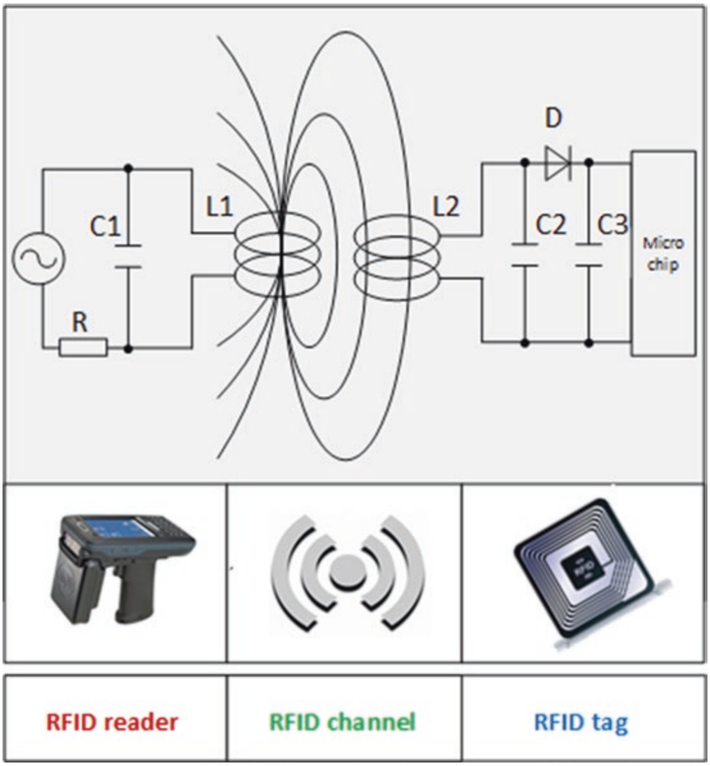

Fig. 1.2 The principle of RFID

tags is used RFID reader, which can take various forms (mobile terminal, handheld reader, stationary gate, etc.) A control system that provides bulk processing of read tags within the reader's reach and the transfer of data to a bound information or control system is called middleware [4, 5].

The basic RFID system (see Fig. 1.2) consists of RFID tags made of microchips with an antenna and a reader with an antenna. The reading device broadcasts electromagnetic waves to which the antenna of the tag is tuned. The antenna serves to exchange the data and transmission energy required for the chip, which is the basis of a system for storing and transferring information. For passive RFID tags, the field thus created is used to power the microchip circuitry; for active RFID tags, energy is obtained from the integrated battery. The microchip then creates waves that send the tag back to the reader that converts them into digital form [4, 6].

The maximum read distance for transponders depends on several factors [7]:

- The speed of the tag movement in the read area,
- Use of carrier frequency,
- The distance between the reader and the tag,
- Tag sensitivity,

- Mutual position, orientation, and polarization of the antenna and tag,
- Current conditions (noise, more tags next to each other, obstacles).

Radiation characteristics of the RFID antenna and transponder are very important for RFID system designs. The RFID system will not work well and reliably if these characteristics are not sufficiently overlapped. The overlap of characteristics is necessary for the reader to retrieve the tag. Without this tag and antenna overlap, the practical RFID system is inoperative because the antenna does not receive a return signal and the reader evaluates that there is no readable object in the vicinity. The ideal radiation pattern of antenna is shown in Fig. 1.3, where the individual lobes of the antenna array are shown [7].

The radio frequency of the RFID tag affects its activity (Table 1.1). Low-frequency RFID systems need less energy and its ripple passes better non-metallic materials; however, their working range is relatively small. Higher frequencies increase the energy demands of the broadcast and the cost of the entire system. The

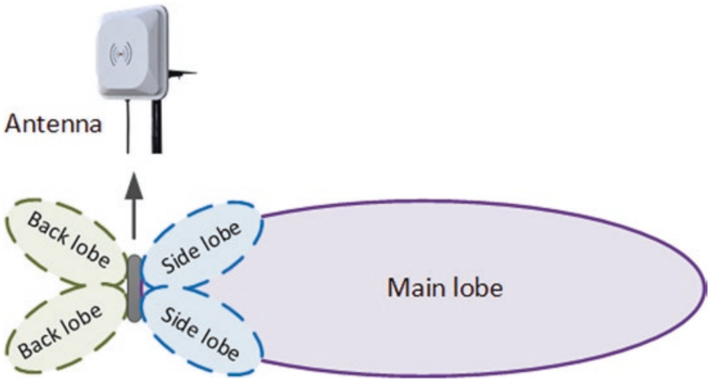

Fig. 1.3 Ideal radiant characteristic of antenna

Table 1.1 Frequency of RFID system based on tag type

	Tag type			
	HF tag	LF tag	UHF tag	MW tag
Frequency	High 13–56 MHz	Low 125–148 kHz	Very high 860–950 MHz	Microwawe 2.45–5.8 GHz
Range [m]	0.5–1	0–0.5	1–3	3–10
Production costs	High	High	High	High
Scanning speed	Sufficient	Low	High	Possibility of extremely high
Shooting options	Difficult scanning through the liquid	On the metal, through the liquid	It cannot be scanned through the liquid, difficult scanning on the metal	The danger of zero standing waves

advantage is that there is an increase in the working range and also a faster exchange of data between the reader and the tag. By using active tags, it is possible to get a working range of several dozen meters. Thanks to high transmission speeds, the system can be deployed to fast-moving production (e.g., electronic road toll). With high frequency systems is transfer of data faster and more read-out than with low-frequency systems. The disadvantage is higher power consumption and poor signal throughput through obstructions. Because of this, there is a need for direct visibility between the tag and the reader [5, 8].

1.3 Measurement Methodology and Laboratory Conditions

Companies engaged in designing RFID systems for custom looking at everything needed to operate the system from the antenna, reader, software to transponders, but each application to the real world is unique to its distribution and layout of interfering elements that the system does not work on 100% at some time. According to the chronology after making the design and documentation follows the implementation of the proposed system in practice, where the system must meet all the criteria set by the client, but in the first place the grouping of the elements must be functional and reliable. After a subsequent run, many times it turns out that the system is not working reliably, so that reading RFID tags is not constant or transponders do not load at all. After this finding, in most of these cases the antenna location changes because its range is not sufficient, and the RFID transponder is not loaded. In the latter case, additional antennas are added due to insufficient coverage area. In order to incorporate component parameters into simulation models and to avoid implementation problems in practice, measurements were performed to verify the ability to read RFID tags in a laboratory environment, but with conditions close to real practice on the mobile device [5, 7, 9, 10].

The experiments conducted at the Department of Industrial Engineering and Informatics have been dealt with on the basis of practical requirements for RFID systems, where the correctness of reading is influenced by many factors. Since many businesses nowadays design and subsequently install information system based on RFID into practice, progressing by system try-mistake and pay little attention to loading intensity, focusing only on whether the system works and identifies the tag.

Measurements were performed in a laboratory, where is not a ideal environment – especially the reinforced concrete structure in the ceiling and floor area, as well as in the ceiling area is the electrical lighting and electrical installation. It all affected the results. For the measurements, an area was graphically labeled. This is a 4.5 × 5-meter chessboard, evenly distributed every 0.5 m along its length and width. This division formed 90 squares (0.5 × 0.5 m) and 110 interpolation points were formed by intersections (see Fig. 1.4). The tags were fastened using a telescopic stand and perpendicular to the intersections of the resulting surface.

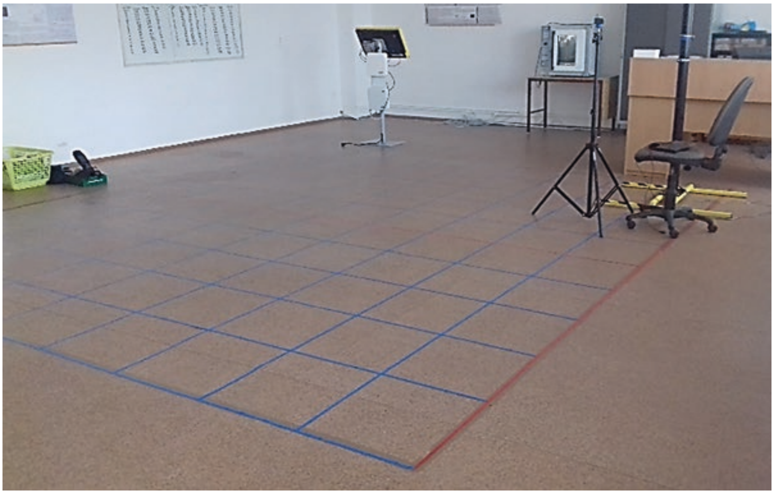

Fig. 1.4 Equipment Gaben TOUCH 24 with Reader Speedway R420 in laboratory with measuring area

The following environmental factors were identified in the measurements:

- Humidity: 53%,
- Temperature: 21 ° C,
- Pressure: 101 kPa.

The following devices and programs were used to measure:

- Lab computer Gaben TOUCH 24",
- Antenna symbol AN480.
- Laboratory stand Unomat.
- Speedway R420.
- MultiReader software (version 6.6.10).
- Three tags (Siemens SIMATIC RF620T tag, UPM tag RAFLATAC DogBone 188_2, Confidex Ironside ™ global M4QT tag).

In Fig. 1.5, you can see graphical interpretation of the 3D space of the measuring surface. The figure expresses the ability to load information by the tag in individual sectors of the space. Each color represents a range of probability (or quality) of reading, which is dependent on the amount of information that are read by using RFID tags. To facilitate the identification of individual probabilities, it was created 10 color scales in total. Fig. 1.6 presents individual color scales according to the efficiency of the information retrieval.

Fig. 1.5 Graphically displayed color ranges depending on number of readings (3D view)

Fig. 1.6 Color marks based on the interval of the reading efficiency

Interval of the reading efficiency (%)	Color mark
90-100	
80-89,99	
70-79,99	
60-69,99	
50-59,99	
40-49,99	
30-39,99	
20-29,99	
10-19,99	
0,01-9,99	
0	

1.4 Results of Experimental Analysis: Measurement of Radiant Characteristics

The aim of the measurements was to verify the ability to read 3 types of passive RFID transponders (UHF tags) under laboratory conditions and to identify the ideal loading limit (95% confidence limit). The tracked element is a qualitative parameter that expresses the number of readings of the RFID tag surveyed per count (TotCnt). RFID tags were tracked at different heights, ranging from 0 to 3 m in 0.5 m increments. The measurements were made as follows: progressively we moved from the first point of the measuring area (chessboard) to the last one. At each point, the tag stand was placed on the given place. The necessary data for the given measured location at the desired measured height were read with using the software in computer. Altogether, 2310 measurements were made on three RFID transponders, the

Table 1.2 Overview of the individual tags and their technical parameters

Tag type			
	UPM RAFLATAC DogBone 188_2	Siemens SIMATIC RF620T	Confidex Ironside™ Global M4QT
Operating frequency	860–960 MHz	860–960 MHz	860–960 MHz
Max read distance	6.1 m	8 m	9 m
Memory type	–	EEPROM	EEPROM
EPC memory	96 bits	96 bits	128 bits
Class	Class 1	Class 1	Class 1
User memory capacity	32 bits	64 bits	64 bits
Weight	1 g	18 g	22 g
Safety standard	–	IP67	IP68
Dimensions	93 × 23 mm	127 × 38 × 6 mm	51.5 × 47.5 × 10 mm

results being to be used for the informatization process in practice. The technical parameters of the individual tracers are shown in Table 1.2.

1.4.1 Results of Measurement for Tag Siemens SIMATIC RF620T

The company Siemens is globally known as a manufacturer of components for power engineering, automation, and others. We have selected the SIMATIC RF620T transponder from the tags that this company produces. This tag is intended for industry, so it should accomplish industry requirements. The manufacturer claims that this tag is resistant to the environment's influences, in which it is located. That is the reason why his products are used to label containers, pallets, and so on. An advantage is also its construction, which allows exploitation in the food industry [11].

Measurements for this tag type were performed according to the above procedure. Fig. 1.7 is a plot of the radiant characteristic measured at individual points of the measuring surface at a height of 0 meter. Anomalies (places with positive intensity of reading) that can be seen on the radiant characteristic can be caused by the floor (its inequalities, etc.). This could lead to tilt of the antenna.

Fig. 1.8 shows the radiant characteristic of the transponder at a height of 1.5 m. Almost the entire measuring area was measured with some probability. Places with light green color could be measured due to lower tag quality and reliability. A radiant characteristic for a height 3 meter is shown in Fig. 1.9. The transponder's response is either excellent or zero. The zero response was causing the reinforced concrete structure of the walls, but also the electrical conduction that is mounted in the ceiling.

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	150	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	152	0	0	0	0	148	0	0	0	154	0
4	0	0	0	0	0	0	0	154	0	0	0
5	0	154	154	0	154	154	154	0	154	0	0
6	0	0	0	0	0	150	150	0	0	0	0
7	0	0	0	156	154	154	154	152	0	0	0
8	0	0	154	154	154	154	154	154	0	0	0
9	0	0	154	0	0	154	154	154	154	0	0
10	0	0	0	0	154	154	154	0	0	0	0

Fig. 1.7 Siemens SIMATIC R620T—Radiant characteristic at height 0 m

	1	2	3	4	5	6	7	8	9	10	11
1	141	137	143	139	0	140	134	143	129	135	130
2	148	142	139	137	136	140	135	144	0	132	0
3	0	0	142	140	141	143	140	0	142	149	139
4	0	147	140	140	140	143	151	142	146	140	144
5	147	149	146	139	133	141	137	140	141	0	144
6	149	146	140	142	134	136	139	141	135	0	0
7	154	151	150	136	142	134	0	139	144	150	153
8	148	147	144	137	140	156	134	0	0	151	151
9	147	147	0	142	135	127	149	151	0	156	156
10	0	153	151	0	147	x	135	136	147	151	0

Fig. 1.8 Siemens SIMATIC R620T—Radiant characteristic at height 1.5 m

	1	2	3	4	5	6	7	8	9	10	11
1	0	146	146	156	156	156	146	149	146	155	146
2	156	156	146	156	154	146	146	146	156	146	146
3	153	0	155	156	0	0	146	146	0	146	0
4	156	0	0	146	146	0	146	0	0	146	156
5	0	146	0	156	146	156	156	152	146	0	146
6	146	146	155	156	146	156	146	146	156	147	0
7	155	156	0	0	146	146	146	154	156	0	146
8	156	0	0	0	0	146	0	0	146	0	153
9	150	0	0	0	0	146	0	146	146	156	0
10	0	0	0	0	156	x	146	0	0	152	0

Fig. 1.9 Siemens SIMATIC R620T—Radiant characteristic at height 3 m

1.4.2 Results of Measurement for Tag UPM RAFLATAC DogBone 188_2

The manufacturer of the UPM RAFLATAC DogBone 188_2 transponder is UPM RAFLATAC, which offers products mainly for the food and pharmaceutical industries. This particular tag type is designed to mark crates and pallets. Since this transponder is made from paper, its design does not allow it to have such a large capacitor as the Siemens SIMATIC R620T tag. This fact resulted in the tag being unable to accumulate similar amount of energy as first tag. That is a reason why tag has a low ability to load information at a height of 0 m (Fig. 1.10) [12].

Fig. 1.11 shows the radiation characteristic of the transponder at the height 1.5 m. Although at this height there was no interference at the height 0 and 3 m, but we also see anomalies (row 4). At a height of 3 m, the effects of the construction of the walls were again reflected, as can be seen in Fig. 1.12.

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	155	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	155	156	156	0	0	0
9	0	0	0	0	0	0	156	156	0	0	0
10	0	0	0	0	156	156	0	0	0	0	0

Fig. 1.10 UPM RAFLATAC DogBone 188_2—Radiant characteristic at height 0 m

	1	2	3	4	5	6	7	8	9	10	11
1	147	136	141	154	147	148	141	144	142	142	142
2	150	156	148	143	142	138	0	145	0	140	150
3	148	0	146	148	0	147	147	0	148	154	0
4	0	0	0	0	0	0	144	0	146	0	154
5	0	154	0	147	154	148	150	149	147	146	148
6	0	152	154	153	148	144	152	140	0	0	0
7	0	0	0	149	146	144	146	0	149	0	0
8	0	0	149	147	146	148	147	148	0	0	0
9	0	0	0	0	147	148	146	146	0	0	0
10	0	0	130	154	146	x	146	154	0	0	0

Fig. 1.11 Radiant characteristic of UPM RAFLATAC DogBone 188_2 at height 1.5 m

	1	2	3	4	5	6	7	8	9	10	11
1	156	156	152	156	156	153	0	156	0	0	0
2	0	0	0	146	0	0	0	145	145	0	0
3	0	0	0	0	0	0	0	145	155	0	0
4	154	0	0	0	0	0	0	0	0	156	0
5	0	0	0	0	0	145	145	0	0	146	0
6	0	148	0	146	144	144	156	146	0	0	0
7	0	0	0	0	0	145	145	0	0	0	0
8	0	0	0	0	0	0	0	0	0	156	
9	0	0	0	0	0	0	0	0	145	0	0
10	0	0	0	0	0	x	0	0	0	0	0

Fig. 1.12 Radiant characteristic of UPM RAFLATAC DogBone 188_2 at height 3 m

1.4.3 Results of Measurement for Tag Confidex Ironside™ Global M4QT

Confidex, a manufacturer of the Confidex Ironside™ Global M4QT tag, is devoted to property and goods tracking, as well as non-contact authentication by the use of RFID, smart tickets, and other. The transponder is designed for placement on metal objects and under more demanding conditions such as humidity and temperature (high or low) [13].

Fig. 1.13 shows the measuring area surface at the tag position of 0 m. From the picture it is clear that the tag was able to load the information directly in front of the antenna stand and in the center of the measuring area. Measurement results of 1.5 m are similar as for the previous tags (Fig. 1.14).

At 3 meters, the magnitude of the signal reflection was not so great, so the measured points are more at the back of the measuring surface. The remaining measured points (with low probability) are again caused by the construction of the walls (Fig. 1.15).

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	143	142	152	0	0	0	0
4	0	0	0	0	142	144	0	0	0	0	0
5	0	0	0	152	147	149	153	0	0	0	0
6	0	0	0	150	156	154	156	0	0	0	0
7	0	0	0	0	146	156	156	0	0	0	0
8	0	0	0	0	154	156	0	0	0	0	0
9	0	0	0	0	0	153	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0

Fig. 1.13 Confidex Ironside™ Global M4QT—Radiant characteristic at height 0 m

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	146	0	145	0	0	0	146
2	141	147	143	142	132	141	141	143	139	0	0
3	0	0	0	138	141	134	139	136	141	145	133
4	0	146	0	0	142	146	147	0	138	0	142
5	152	147	147	143	0	139	138	143	147	0	0
6	0	0	0	144	141	143	143	156	146	0	156
7	0	0	152	146	136	152	152	134	147	152	0
8	0	0	0	145	155	134	135	145	149	0	0
9	0	156	151	152	145	136	152	148	149	147	0
10	0	0	154	147	147	x	137	0	0	0	0

Fig. 1.14 Confidex Ironside™ Global M4QT—Radiant characteristic at height 1.5 m

	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	153	146	152	0	0	143	147	0
2	0	0	0	0	148	0	0	0	0	148	0
3	0	0	0	152	156	0	156	134	0	0	0
4	0	0	147	147	146	0	147	143	0	0	0
5	0	0	147	0	0	0	145	152	0	0	0
6	0	145	0	0	144	143	147	150	0	0	0
7	0	0	156	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	x	0	0	0	0	0

Fig. 1.15 Confidex Ironside™ Global M4QT—Radiant characteristic at height 3 m

1.5 Conclusions

The chapter contains the outputs of experimental measurements that verified and also identified the quality of RFID tag transmission under laboratory conditions by simulation of the real environment. The results contribute to raising the level of knowledge in the field monitoring of information flow for needs of Industry 4.0.

After performing the measurements, it was found that, under the given conditions, the UPM RAFLATAC DogBone 188_2 transponder showed unsatisfactory results (unreliability, error, instability of the load in the measured area) throughout the measurement time. These inadequate results are connected with its technical and design parameters.

Confidex Ironside™ Global M4QT is a type of transponder that is specially made for unfavorable environments with interference elements. This is the reason why the manufacturer has the increased requirements for its functionality and reliability compared to, for example, the previous tag. The measurements showed that the properties from maker (lower error by loading a defined space) are true and therefore these types of tags are suitable for using in manufacturing systems (especially environments with undesirable effects).

The last tag that was subjected to the measurements was the Siemens SIMATIC RF620T tag. This tag has almost twice the size of the antenna as previous tags. This fact manifested itself in an important feature, namely the ability to load. The larger antenna has ensured that the measured values have fluctuated very little. Also, another feature of the transponder has been promoted—an increase in the range of the tracking area, which is a relatively important indicator when using RFID technology. The measurements show that this type of transponder has achieved experimentally the best results, as evidenced by Figs. 1.7, 1.8, and 1.9. The figures show the reliability, but also the loading stability at the height of 0 m (floor), 1.5 m and 3 m (ceiling). The red color indicates a 0% loading efficiency, a light green efficacy interval of 80–89.99%, and a dark green 90% or more.

Since the measurements were performed under real conditions that were not modified (due to adverse effects—iron-concrete construction of the building and electro installation), the results are comparable to what would be the loading of the individual tags in companies where they have similar undesirable effects. The results indicate that the ability of reading or loading information with the use of Confidex Ironside™ Global M4QT and the Siemens SIMATIC RF620T is such that it is better for environment where there are disturbing effects. Of course, other factors, which have not been observed in the laboratory experiment, can be in practice showed, so it is advisable to implement the tags in a specific process (operation) and to investigate further their functionality and properties under the given operating conditions.

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Chapter 2
Heros and Cunctators of Sustainable Development

Janusz Grabara

2.1 Introduction

Depending on the scientific discipline represented in which sustainable development is talked about, its definitions are described in very different points of view and there are a lot of them [1–3]. The first internationally recognized definition of sustainability was created by the World Council of Environment and Development [4]. That defines sustainability as "the development that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs." This means today's actions have corresponding effects to future generations [5]. Considering the "definitions of sustainable development," one can say that it has many definitions, because it depends on economic, environmental, and social factors; each of these factors creates its understanding of the issue of sustainability [6]. The question is so multidisciplinary that one can speak about philosophy of sustainable development [7].

At the moment the concept of sustainable development has become the key to positive consideration of any project [8–10]. As long as the definition of sustainable development appears in the project description, the chances of obtaining funding for the project are increasing several times. The reality is that it is not known what this sustainable is. Michael D. Lemonick the senior writer at Climate Central, a non-profit climate change think tank in Princeton, N.J. in his article "Top 10 Myths About Sustainability" suggested that it is not known what sustainability means [11]. The article points to certain shortcuts that have no reference to the reality:

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- Nobody knows what sustainability really means.
- Sustainability is all about the environment.
- "Sustainable" is a synonym for "green" [12].
- Considering recycling process - Sustainability is too expensive
- Sustainability means lowering our standard of living.
- Consumer choices and grassroots activism, not government intervention, offer the fastest, most efficient routes to sustainability.
- New technology is always the answer.
- Sustainability is ultimately a population problem.
- Once you understand the concept, living sustainably is a breeze to figure out.

It is not difficult to get the impression that the concept of sustainable development is understood in the most convenient way for the one who creates it.

It is necessary to clearly define the division into heroes and cunctators of sustainability processes supporting sustainable development. In this place you can designate heroes, that is, the Sun, geothermal heat and wind, but the Sun has a huge meaning in this statement. The purpose of the publication is an introduction to the discussion on the effectiveness and economic efficiency of sustainable development.

2.2 Sun Heros of Sustainable Development

Since the dawn of the Earth's history, it has always been accompanied by the Sun. Everything that lives and grows on Earth is the result of the Sun's influence. It is an inexhaustible source of energy on a trans-civilization scale, and very importantly free of any charges.

Wikipedia reports that solar radiation reaches the upper layers of the Earth's atmosphere with a radiation intensity of 1366.1 W/m^2. This means that the total power reaching the atmosphere is about 174 petawatts. About 30% of this power is reflected immediately into space, and another 20% is absorbed by the atmosphere. Approximately 89 petawatts reach the Earth's surface, which means about 180 W/m^2 on average. This power is not evenly distributed: an area illuminated by light falling perpendicularly from above can receive up to 1000 W/m^2, while the areas in which it is nighttime do not receive anything directly. After averaging the diurnal and annual cycles, the most energy is given to areas at the equator, and the least are circumpolar regions. The total energy that reaches the horizontal surface throughout the year is from 600 kWh/(m^2 × year) in the Scandinavian countries to more than 2500 kWh/m^2/year in central Africa. In Poland, it is about 1100 kWh/m^2/year.

It is an energy that does not generate hazardous waste, ash dumps, or other byproducts. The problem is only skillful use of this energy. Skillful use in the sense of achieving such technological solution will make the use of solar energy economically viable [13]. So far, solar installations like winds do not actually pay for the costs of building and operating them, and they only exist in projects funded by governments and organizations. Most often, this refers to the production of electricity, which is constantly a problem when considering its storage on an industrial scale. It is much easier to store natural fuels such as coal, crude oil, and natural gas.

2.3 Coal Still the Current Star of Electricity Production

Identifying the star for carbon in the area of sustainable development is in the pejorative sense. Nevertheless, according to statistics, it is coal that most electricity is produced from. Data of energy production show energy produced in 2018 since first January (in kWh) until 30-10-2018 (Fig. 2.1), source [14]. Renewable energy (excluding hydropower) accounts for only 4.2% of electricity production worldwide. Electricity generation in hydroelectric power plants, the oldest renewable energy sources, generates 15.6% of total electricity.

Nuclear power plants produce almost 12%. In France, about 80% of power comes from nuclear power plants. Worldwide, 41% of the electricity comes from coal (43% in the USA). China produces 4715.7 TWh /year, which accounts for 79% of all electricity in poorly regulated power plants. These statistics come from World Bank reports [15]. The value of electricity generated from renewable sources is only 4.2% of global production. So we can qualify as a small rising starlet in sustainable development. However, the question remains whether the growth of this star will be so large in the coming years to meet the increased demand for climate warming and the introduction of new energy efficiency solutions such as electric cars and other such solutions. "The Guardian" published data compiled by the British operator National Grid, a significant increase in the number of electric cars in the UK could result in peak power demand by 2030 surpassing the capabilities of its power system, supplemented even by the Hinkley [16]. By 2030, the number of passenger cars and vans in the UK is expected to reach 9 millions. At present there are 90 thousand of them. Loading too many car batteries would have the effect of reversing the declining trend in demand for energy in recent years [17]. This is related to activities undertaken to increase energy efficiency [18]. If electric vehicles will not be loaded in such a way as to avoid peaks and falls in power demand, for example during the hours between five and six in the afternoon when people return to homes,

Fig. 2.1 Sources of electricity production

then peak demand for power can be up by 8 GW. Moving the charging time for a period when the energy demand is lower could reduce the peak demand for power to 3.5 GW. It's less than in the previous scenario, but it's still about the same size as the Hinkley Point C (3.2 GW). In this simple example, it can be said that making changes without prospecting increasing demand for electricity can lead to severe system failures, in this case. So global electricity generation will continue to rely on coal for many years to come. Therefore, we cannot now talk about sustainability in electricity production, as fossil sources such as the star Coal and about half the stars of the Oil and Gas are dominant in this area. And renewable energy sources are tiny rising starlet with a small share of less than 5% in electricity generation worldwide.

2.4 Population the Current Cunctator Food Production and Life Level

Considering important factors, such as sustainable development, the demographic factor cannot be ignored. Demography is definitely a cunctator; it is difficult to pinpoint what has a negative impact on sustainable development. Figure 2.2 World population at 30-10-2018

Over 7.5 billion people live in the world right now. The United Nations (UN) long-term forecasts for 2100 are to have 11 billion people on Earth. Half of the world's population lives on only 1% of the land area. Half of the population resides in Asia, population dispersion is steadily decreasing [17]. In Tokyo, the capital of Japan, with suburbs there are more than 40 million people, which is more than in Poland. Most of us are in temperate and subtropical areas. The farther to the poles, the smaller the population, and all indications are that it will stay that way in the future, unless there are some drastic climate changes waiting for us. According to the UNDPD statistics, by 2100, the population of Africa will definitely increase and the rest continents of the will be on the same level. Although the earth is still not

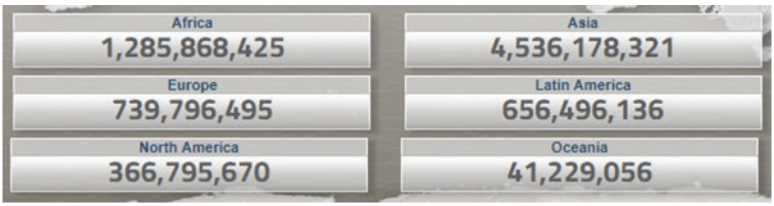

Fig. 2.2 World population in 2018 Prospects 2017

overcrowded in terms of space occupied by us, it is due to problems with food production, overfishing of fish, soil and air contamination, and the use of mineral resources [19]. Therefore, demographic policies related to population growth and food insecurity for this population should be conducted on a global scale, which is unacceptable in today's circumstances and is not a factor in star status. Stars are definitely far from sustainable development.

2.5 Conclusions

The considerations presented in this paper are intended to stimulate discussion and possibly coordinated action in the area of approaching sustainable development. Since the current activities are implemented on a micro scale and locally. There is no clear and common policy supporting the pursuit of sustainable development. One of the reasons is a cunctator called an economy. In principle, all countries in the world are indebted so a large proportion of their revenues are devoted to debt servicing and the implementation of current affairs relevant to the state or to meet the needs of the population. In this case, the global action or near-indefinite execution date goes to a further plan [14].

As shown in Fig. 2.3, budget deficits of the largest countries are close to GDP. Such a state of affairs means that decisive and effective actions in pursuit of regional development do not have global support. The economy cunctator is almost as strong as the SUN star, with the only difference being that the Sun has no influence and that is a positive aspect, and the economy is influenced by politicians and also most often affected by it.

Fig. 2.3 Selected countries' debt situation. Source [14]

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Chapter 3
Acquisition and Processing of Information from Slovak Publicly Available Data

Romana Hricová and Stanislav Adamčík

3.1 Introduction

Every entrepreneur wants to protect his business, and in addition, by examining not only existing but also potential business partners. This way, using credible information, it can be timely to see if a business partner, for example, has financial problems. It can respond more quickly to the situation and protect your own business. Verification, continuous retrieval and evaluation of information become the regular routine needed for successful business. This information can now be obtained mainly from public registers. The entrepreneur is thus able to verify the management information, ability to pay commitments, payment discipline, and more about his or her business partner or potential partner. The most up-to-date information is provided by official journals and economic periodicals. All the publicly available information from different registers, newsletters, and financial statements can be generally obtained by the entrepreneur in two ways. In a more interminable way from a variety of sources, but for free; or more comfortable and, of course, much faster, but from a commercial source, what means for a fee. Entrepreneur must pay for re-searching or other searching again. There is also the opportunity to use professional information providers who appear to be the most expensive.

The truth is that every production unit that wants to be competitive in the present day should be characterized by a suitable combination of needed productivity, flexibility, and quality [1]. But companies on the other hand understand how important is to know as much as possible about business partners as well as competitors for their competitiveness.

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In this context, small- and medium-sized businesses are more problematic because the financial data of this group of companies is mostly missing from public resources. Despite the fact that the situation has improved, the statutory obligation to publish financial statements and to keep them in the collection of documents still accounts for approximately half of Slovak companies and the financial data of the self-employed who charge in the system of simple accounting in public sources are not at all. Registers usually provide only contact information.

On the other hand, the entrepreneurs very often receive information which is not appropriate or necessary to them or they are not in the form they would need.

However the most valuable information becomes those that are from official sources, but it is also necessary to consider whether the concerned subjects have a legal obligation to pass on the information and how that information is accurate. Information from official sources is much valuable since these data are not only from the sample of respondents but from the basic set, i.e., all entities that are required to publish this information. Plus very important precondition for a successful company application in the business environment is its ability to archive relevant data in the long term on the basis of management quality systems, exactly according to the requirements specified in concrete conditions [2].

Finally the pressure on public information, on increasing transparency requirements and the requirement to have the most accurate information in the shortest possible time, yielded results. There is good trend in publishing data by state entities in Slovakia and it can be said that 2016 was a breakthrough in data disclosure. The main reason for this breakthrough was the launch of the slovensko.digital platform.

3.2 Groups of Data Providers

Providers of publicly available data can be divided to three main groups:

1. State entities
2. Independent organizations
3. Enterprises

3.2.1 State Organizations

The State Administration is the first provider of publicly available data. It also determines what everything can be published. Act no. 211/2000 Coll. On Free Access to Information and on Amendments to Certain Laws (Freedom of Information Act) [3] states that the persons required by this Act to make information available are state authorities, municipalities, higher territorial units as well as those legal persons and natural persons to whom the law entrusts the power to decide on the rights and obligations of natural or legal persons in the field of public administration, and only to the extent of their decision-making activities.

When checking a business partner, it is usually necessary to start by checking the registration data, the most important of which is the business name, identification number (company ID), registered address, legal form, and statutory representative. These data can be verified in the registers maintained by the Ministry of Justice of the Slovak Republic.

3.2.1.1 Registers Maintained by the Ministry of Justice of the Slovak Republic

The Ministry of Justice maintains and makes available information on companies in the Business Register (www.orsr.sk). In the trade register of the Slovak Republic at www.zrsr.sk can be found information about the self-employed persons. There is information about Civil Associations, the Interest Associations of Legal Persons, Associations of Municipalities, Non-investment Funds, Non-profit Organizations, Political Parties and Political Movements, Associations of the Owners of Residential and Non-residential Premises Organizations with the International Element, and finally Register of Foundations at http://ives.minv.sk/rez/registre/default.aspx [4]. All information obtained from these registers is informative only and is not filled in online. It is possible to search for entities by name, identification, the registration number, the surname and the name of the natural person, and the location where they are located. User can search for all records or only those that are current.

Under the Ministry of Justice of the Slovak Republic is also operated the Commercial bulletin [5], which provides the following data:

- Business register
- Collection of documents
- Notices of initiation of winding-up or co-operation proceedings without liquidation
- Bankruptcy and restructuring
- Claims of liquidators
- Other announcements
- Specification of received share of income tax paid
- Auctions
- Sale of property
- Management reports
- Mandatory published contracts

For the general public, this information is available in PDF format and registration is free of charge. Data is updating every working day. The portal of the Ministry of Justice also has the opportunity to register for an account, to access structured data that can be subsequently processed by computer. This option is used by many businesses and organizations. This creates complex databases of publicly available data. Fig. 3.1 shows search page of the Commercial bulletin [6].

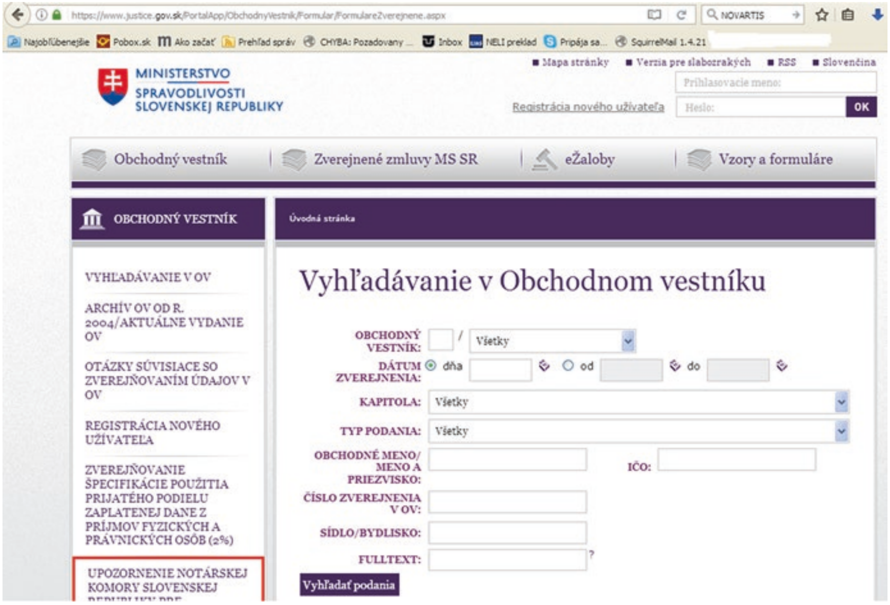

Fig. 3.1 Search page of the Commercial bulletin [6]

3.2.1.2 Statistical Office of the Slovak Republic

Statistical Office of the Slovak Republic is the oldest source of published data and the conditions for obtaining the necessary information are regulated by Act No. 540/2001 Coll. on State Statistics, which entered into force on January 1, 2002. Pursuant to this Act, a legal entity or a natural person who is a reporting entity is obliged to provide free of charge, fully, truthfully and within specified dead-lines, the data required by the State Statistical Surveys, which are listed in the State Statistical Surveys Program.

Statistical Office offers **DATAcube—**the classification system of individual tables is based on maintaining the structure of domains and fields similarly as in the web portal. Data from various statistical fields are presented in the form of multidimensional tables in monthly, quarterly, or yearly time series and allow creating your own selections. At the end of the title of each table there is eight-digit code, which is the unique identifier. The outputs can be exported to file formats: PDF and XLS [7].

The Statistical Office of the Slovak Republic publishes the available data in open formats with a text description of the published data content, based on the Government Resolution of the Slovak Republic No 59/2015 of February 11, 2015 approving the Open Government Partnership Action Plan of the Slovak Republic 2015 [7] (Fig. 3.2).

It is possible to check the business partners in the organization register on the website of the Statistical Office of the Slovak Republic, but only in particular because it is not connected to the business or trade registry, which is a considerable

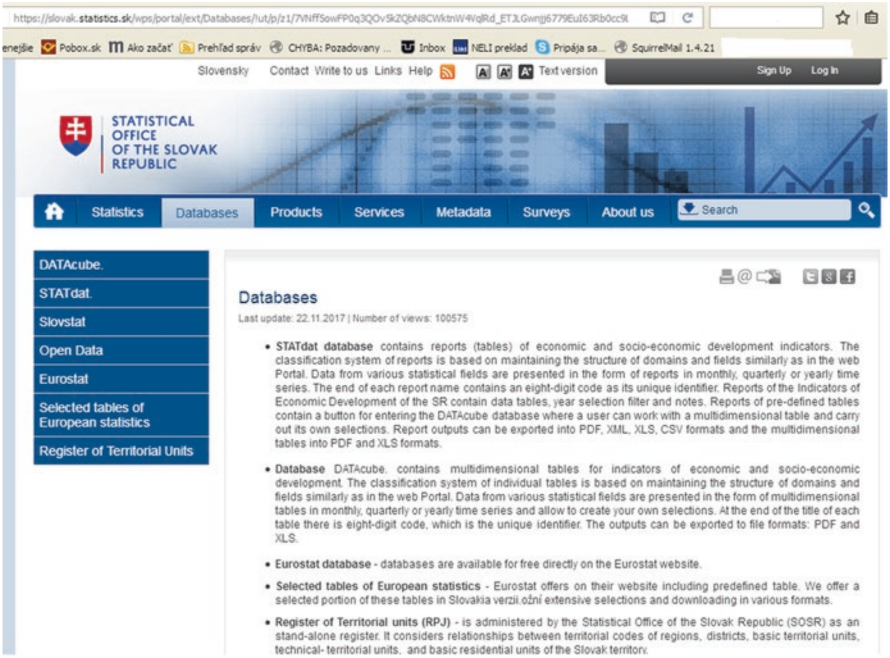

Fig. 3.2 English page of Statistical Office of the Slovak Republic with link to open data [7]

disadvantage. Incompetent co-operation with registry courts is due to the fact that changes to entries in the business register appear in the register of organizations with a delay. Sometimes there is a shorter time in the missing entities, or the deleted ones are still missing.

This most extensive economic register of all legal entities that have an ID in the SR is the only one that has some information transferred to the codes. That's why he searches and sorts well in it. All used classifications and dials are available for free.

3.2.1.3 National Agency for Network and Electronic Services

The National Agency for Network and Electronic Services (NASES) was established on January 1, 2009 as a contributory organization of the Government office of the Slovak Republic in order to fulfill professional tasks in the field of Informatization of Society, management and operation of electronic communications networks and services for other government bodies, legal entities and natural persons, who require information and data from information systems, databases, and public administration registers [8].

Activities of NASES support development of e-Government services in Slovakia. This activity leads to improving the effectiveness of the public administration performance and simplifying interaction between citizens and authorities, as well as supporting the information knowledge base of the society, public sphere, business community, and the general public [8].

The key tasks of NASES are: [8].

- Organizing, operating, and development of GOVNET network,
- Operating sTESTA network at Slovak Republic,
- Operating and development of central governmental portal (www.slovensko.sk),
- Operating and development of information system for registration and payment of administrative and court fees,
- Operating and development of central customer service of Slovak Republic,
- Administration, operating, and development of national cyber security systems.

NASES operates the open data portal data.gov.sk as well, which was created under the Open Government Initiative, which aims to improve governance and management of public matter through increasing transparency, efficiency, and accountability. Data.gov.sk is a catalog containing various datasets from obligated persons in the Slovak Republic. It is possible to collect data links from the site for private use, or search in published data. The open data portal is able to store a copy of the data or provide them with a database space along with basic visualization tools based on the type of data and the form of use. Specific datasets can be found at https://data.gov.sk/dataset. There are 1531 different datasets from multiple organizations at present (November 2018). These datasets can be searched for and filtered by organizations, keywords and expressions, file formats, licenses, and the specified sequence on the portal, and there are available in different file formats. The largest representation is CSV and XML.

3.2.1.4 Social Insurance Agency

The Social Insurance Agency [9] provides only a database of debtors. Data is in two formats: TXT and CSV.

3.2.1.5 The Ministry of Finance of the Slovak Republic

The Ministry of Finance of the Slovak Republic maintains a Register of Financial Statements [10]. The Register of Financial Statements was created to improve and simplify the business environment and reduce the administrative burden on business. At the same time, it should improve the availability and quality of information on accounting units. The Register is established by Act No. 431/2002 Coll. on Accounting as amended. The register is an information system of public administration, operated by the budget organization DataCentrum, Bratislava [10].

The Register started to perform its tasks from January 1, 2014 and obligatorily publishes the accounting documents pursuant to § 23 par. (2) of the Act, drawn up on December 31, 2013 and thereafter. Using the web site, users can:

- Search in the list of accounting units.
- View available financial statements and other documents published in the register.
- View, save, and print financial statements and other documents published in the registry [10].

However, a more in-depth investigation will show that not every company is likely to upload the requested data or submit it in the required format as some data shows "Data not available in a structured form."

3.2.1.6 Central Register of Contracts

The Central Register of Contracts [11] is the website on which contracts concluded by the liable entity (pursuant to §5a of Act No. 211/2000 Coll.) are published [3]. A publicly disclosed contract involving the Ministry, the other central state administration body, a public body and a budgetary organization or a contributory organization established by them, which are liable pursuant to Article 2, shall be published in the Central Register of Contracts; the liable entity shall immediately send to the Office of the Government of the Slovak Republic a contract for publication. The Central Register of Contracts is a public list of mandatory contracts, which are maintained by the Office of the Government of the Slovak Republic in electronic form. Register is a public administration information system. In this register is today approx. 1,757,453 contracts (November 2018).

3.2.2 Independent Organizations

Publicly available data set up by private companies obtains and processes information from state institutions. These organizations receive data from the state administration, trying to consolidate them. The most distinguished providers include:

3.2.2.1 Platform Slovensko.Digital (Slovakia.Digital)

Slovensko.digital is a civil association aimed at enhancing the quality of digital services in Slovakia. The members of the association are mainly IT specialists. Since the start of their foundation, they have launched more successful projects. In the area of public disclosure, this is the following:

- ekosystém.slovensko.digital [12] (ecosystem.slovakia.digital)
- verejne.digital [13] (public.digital).

Ecosystem.Slovakia.Digital [12] This project is so far the most significant that the slovak.digital platform has put into operation. It includes services:

- Datahub [14].

The service provides access to consolidated and linked structured data via a simple REST API. Using REST API is beneficial for businesses as well as individuals who can use this data in their information systems. The user no longer has to rewrite the published data from the Internet; the service will be delivered automatically. However, the information system must be adapted to communicate with the web service. For advanced data analysis, it is also possible to access the SQL database. Registration is required here.

- Open data & API.

Open data are in this case SQL databases that are really made available to the general public and are freely available for download. Currently there are the following databases:

– *Register of legal entities*—Database of legal persons, entrepreneurs, and public authorities. There are more than 1.4 million legal entities with complete history.

Source: Register and identifier of legal entities, entrepreneurs, and public authorities, Statistical Office of the Slovak Republic.

– *Central Register of Contracts*—Database of contracts of the central register of contracts since 2011.

Source: data.gov.sk, Central Register of Contracts, Office of the Government of the Slovak Republic.

– *Bulletin of Public Procurement*—Public procurement database from 2014.

Source: data.gov.sk, Bulletin of Public Procurement, Office for Public Procurement.

– *Commercial bulletin*—Database of notices from commercial bulletin since 2011.

Source: Commercial bulletin, Ministry of Justice of the Slovak Republic.

– *Register of Financial Statements*—Database of accounting units of the register of financial statements.

Source: Register of Financial Statements, Ministry of Finance of the Slovak Republic.

– *Debtors of the Social Insurance Agency*—A database of social insurance debts from 2014.

Source: Debtor Lists, Social Insurance Agency.

– *Debtors of the General Health Insurance Company*—Database of debtors of the general health insurance company from June 2016.

Each of these databases is guided by practical and streamlined documentation (table and column descriptions). Each of them is also available with the REST API, which makes available consolidated and linked structured data in the JSON format.

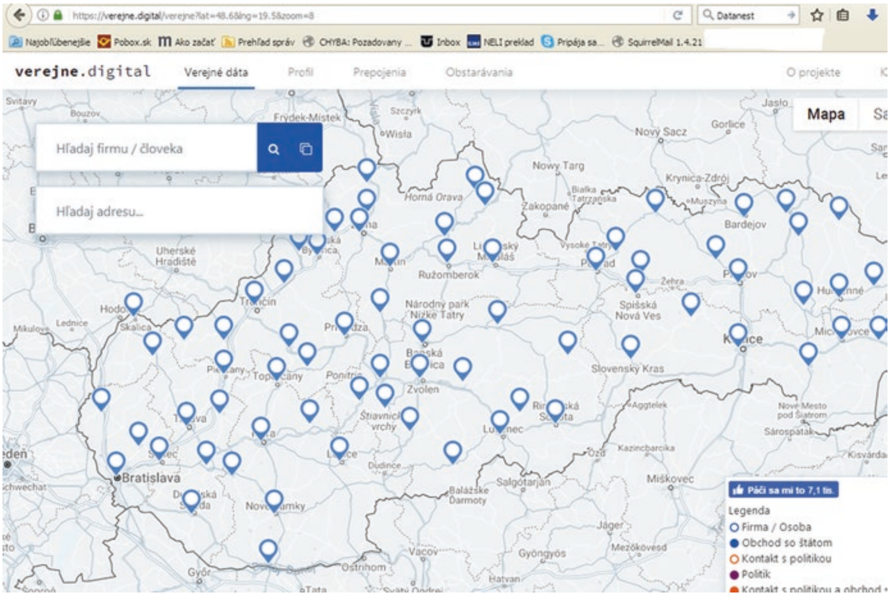

Fig. 3.3 Homepage of the public.digital [15]

Public Digital [13] The service is made available in the form of a website. Its control is very intuitive and simple. Within this project there are two more:

- *links.public.digital* (prepojenia.Verejne.Digital)—The purpose of the service is to search for links between businesses and people,
- *procurement.public.digital* (obstaravania.Verejne.Digital)—The purpose of the service is to identify and notify tenderers who should be involved in public procurement (Fig. 3.3).

3.2.3 Enterprises

According to the Freedom of Information Act [3], disclosure of information may also be required by a separate legal act from another legal or natural person.

3.2.3.1 Company FinStat Ltd.

Company FinStat Ltd. [16] is the entity that publishes financial information about enterprises. The website serves to the public since 2013 and the main data sources processed by the Business Journal, the Trade Register, Registry of Accounts, Lists of Debtors from insurers, Lists of the Financial Report and Court Decisions. They are gradually adding additional data sources, but only a few of these resources are free. The free information that the interested person receives is in a simplified form, and even if they are processed graphically, there is no possibility of finding a more detailed structure.

3.2.3.2 Company Foaf Ltd.

Second private company which provides data about Slovak enterprises is Foaf Ltd. (the name FOAF comes from the English acronym Friend Of A Friend). The project itself draws information on companies from publicly available data from state entities. However, the main ambition is to search for and display deeper connections between people and businesses in Slovakia using graph algorithms, so thanks to foaf.sk anyone can easily browse the social network of Slovak businesses and entrepreneurs and see the relationships between them.

As with FinStat s.r.o. Foaf provides only a fraction of the information for free, others have to buy the buyer, and the price list with the services to be paid is published on the Internet.

3.3 Consolidating of Publicly Available Data

As the paper shows above, it is no longer a problem to get data, but that data needs to be verified from a variety of sources, manually traversed and consolidated. If one of the providers offers it, it is a private company that charges this data because it is time consuming. Commercial products, on the one hand, eliminate the handicaps of public resources that are not linked, but on the other hand these services are not free of charge.

In order to use the public data source, the individual must have it available, so they must be downloaded. This is also due to the fact that data resources from the Internet are not ready for immediate use. Therefore, resources must be downloaded and, depending on the format of the data source stored, they need to be prepared for further use.

When attempting to consolidate information from slovak.digital, it turned out that there are data sources in the exported SQL format, so these files need to be downloaded and imported into new databases. This SQL dump is created from PostgreSQL databases.

The following table shows the data source, description, size GZ (GZIP format), SQL size and times needed to download GZ, expand GZ, and finally import SQL (Table 3.1).

The third column indicates the file size; the fourth size SQL—SQL is expanded to the GZ file. This expanded file is then imported into the database, with the import of SQL (most needed) for importing data into databases. The file SQL contains

Table 3.1 Data import from ecosystem

Data Source	Description	Size GZ	Size SQL	Download GZ	Expand GZ	Import SQL
		[MB]	[MB]	[HH:MM:SS]	[HH:MM:SS]	[HH:MM:SS]
BR	Business register	1252.96	2720.46	0:04:39	0:02:34	13:21:48
CRC	*Central register of contracts*	219.43	445.14	0:01:09	0:00:29	1:20:56
PPN	Public procurement notice	322.19	654.61	0:00:27	0:00:38	0:17:31
CB	Commercial bulletin	1565.88	3274.36	0:05:20	0:03:04	3:12:33
RFS	Register of financial statements	95.53	172. 91	0:00:29	0:00:07	0:32:47
SOCINS	Debtors of social insurance agency	4.05	7.32	0:00:05	0:00:00	0:02:29
VSZP	Debtors of the general health insurance company	5.33	10.58	0:00:01	0:00:01	0:03:06
ITMS2014+	Extensive money drawing data from European operational programs	198.14	364.24	0:00:26	0:00:18	0:25:54
SUM		3663.51	7649.62	00:12:36	00:07:11	19:17:04

commands that are sequentially run on databases. So, in the SQL file, the data do not be searched, it needs to be imported into the databases so that the data can be further processed.

If a user is able to create their own file processing program, it will be able to edit and store data in their own form. Subsequently, the data can be exported for further processing. Registers will, for example, serve to create partial databases that are directly on the PC and can be further processed by the user. The imported data can be displayed arbitrarily.

The need for a program is based on the fact that data resources on the Internet are not immediately usable. They must be downloaded and, depending on the format in which the data source is stored, must be prepared for further use. For example, slovensko.digital gives its data sources in an exported SQL format (such as SQL dump) and so these files (data, SQL dumpy) need to be downloaded and imported into a new database. This SQL dump is made from the PostgreSQL database.

The database can be used on a local computer or server (home, business, hosting solution). When local count is used, the data is only accessible on the computer where it is located. Even though it is possible to solve the network problem, but in this case the computer must still be turned on, which is not a good solution due to its subsequent high capacity. If a user chooses for a hosting solution, he/she will have access to the data anywhere. The data source that has been created can be accessed through the client libraries (.DLL) or the HTTP protocol. In our case, HTTP protocol was selected because this protocol can be used on computers, tablets, mobiles, simply on all devices that support the HTTP protocol. If only accessed through client libraries, we would need DLLs (Windows, Linux, Mac) on phones and tablets on each platform, which would be a problem for many users.

Since most of the necessary data is available to users free of charge, if the user can program a program or have access to some appropriate program, the data usage possibilities are unlimited, which is a great advantage for the end user.

3.4 Conclusions

In the growing era of information technology, demands for rapid and accurate information also grow. Business entities no longer want to only provide information but also to obtain it. The first major step forward was the adoption of the Law on Free Access to Information in 2000, prompting state actors begin to disclose information to the general public and withdrawal upward trend continued. The second significant milestone was the year 2016 when the slovensko.digital platform was launched.

However, obtaining and using relevant information may still be financial and time consuming, so it is appropriate to consolidate the data so that it can be used anytime, anywhere without further searching. The article also shows how these data can be consolidated and then used.

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Chapter 4
New Possibilities for Using of Recycled Polyvinyl Butyral (PVB) in the Manufacturing Technologies

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4.1 Introduction

The implementation of materials from secondary raw materials and their application to possible components reduces the economic and environmental aspects that are also important today [1, 2]. The aim of the work is to find areas of use of recycled polyvinyl butyral (PVB) product, which is the product of windscreens recycling. Nowadays, every car and its windshield is equipped with a polyvinyl butyral film that secures the safety of glass. The patent's research [3, 4] points to possible uses of recycled polyvinyl butyral in practice. Polyvinyl butyral (PVB) [1, 2] is a special resin material, mainly used as a raw material for glass laminated safety glass in cars and in the building industry. PVB currently produces several companies in Europe and the world, each under its business name. In addition to the main application and thus the use of PVB films, PVB resins are used for the production of paints, structural adhesives, dry toner paints, and as binders for ceramics and composite fibers [2]. The PVB film has a number of outstanding features such as high tensile strength, impact resistance, transparency, and flexibility, which is particularly useful in the production of safety glass. Due to the alcohol, ester, and acetate bond content, PVB films [3] can hold the glass firmly, even if the glass breaks. The glasses adhere to the interlayers of PVB film to prevent breakage [2–4]. Revenues of primary end-users of polyvinyl butyral are dependent on the performance of the general economy, especially for safety glass, which is so necessary in the automotive and construction industry—in architecture.

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In the market, polyvinyl butyral resins are highly concentrated and are the domain of four companies—Eastman, Sekisui, DuPont, and Kuraray [5, 6] PVB is exported to countries with the expansion of car production. In most advanced countries, such as the United States, Western Europe, and Japan, but also in the Middle East, demand for PVB is still high. In the context of the use of the security foil, it was preferred primarily to areas of architecture, such as laminated safety glass. PVB is a huge potential for the emerging market [4, 5]. The following figure (Fig. 4.1) shows the place of insertion of the polyvinyl butyral sheet between the glass sheets and the formation of the safety glass (or safety windscreen).

PVB film is one of the most important parts in the interlayer of a windscreen or safety glass [4]. Laminated glass, commonly used in architecture and the automotive industry, has a protective interlayer, most of which is a PVB that forms a fuse between two glass sheets [5]. A study on Transparency Market Research shows that land transport was the largest end-user of the PVB segment of the market, accounting for more than 45% of the use rate than in 2014 [6]. Figure 4.2 shows in detail the condition after the windscreen was damaged by impact. It can be seen that the glass does not break, it only shatters and holds the spoil. The material that the glass layers hold together is a polyvinyl butyral foil.

PVB is exported to countries with an extended automotive production. In most advanced countries, such as the United States, Western Europe, and Japan, but also in the Middle East, demand for PVB is still high. In the context of the use of the security foil, PVB was especially preferred to architectural areas, such as laminated safety glass. PVB is for the emerging market an enormous importance. With regard to solar energy, there is a prediction that the fastest growing area of the end-user PVB, with respect to the compound annual growth rate, is projected to increase by more than 6% between 2015 and 2015–2023 [7, 8].

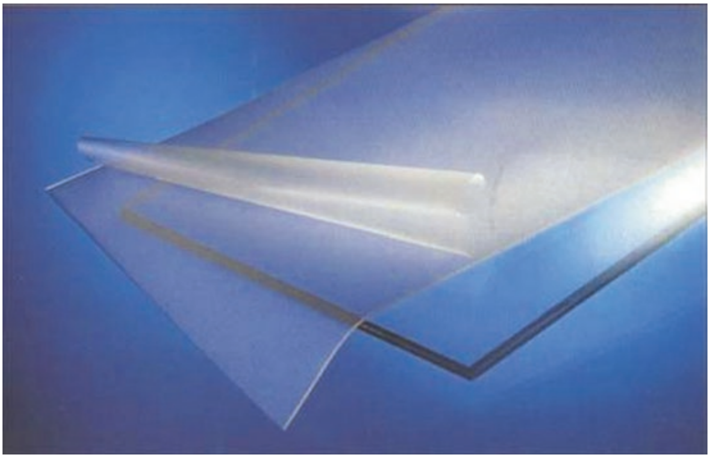

Fig. 4.1 Polyvinyl butyral film as a part of safety glass [8]

4.2 Materials and Methods

Polyvinyl butyral (PVB) [2] is a special resin, mainly used as a raw material for laminated safety glass in cars and in the building construction industry. Application is mainly for skyscrapers. PVB currently produces several companies in Europe and the world, each under its trade mark. In addition to the main application and thus the use of PVB films, PVB resins are used for the production of paints, structural adhesives, dry toner paints, and as binders for ceramics and composite fibers. Polyvinyl butyral, which forms is a safety interlayer in windscreens or glasses of buildings, takes the form (Fig. 4.3) of flakes having dimensions of 2–20 mm and a thickness of 0.5−1.5 mm.

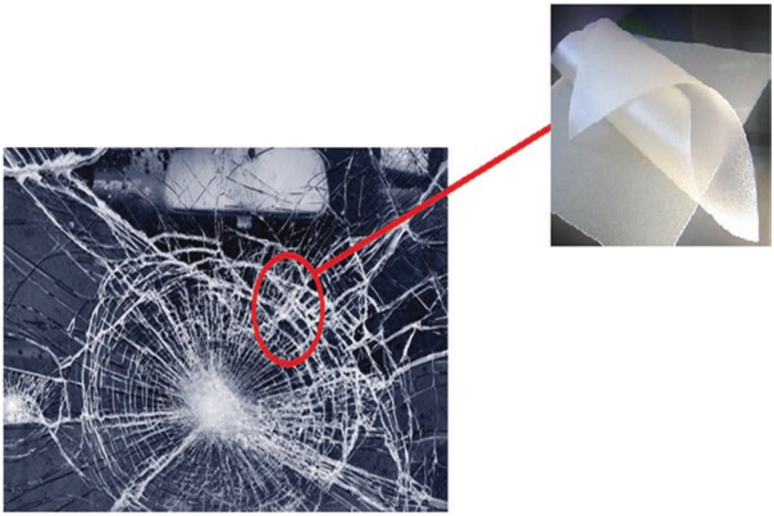

Fig. 4.2 Polyvinyl butyral film as a part of safety windscreen [8]

Fig. 4.3 Recycled polyvinyl butyral in the flakes form [13]

Table 4.1 Material characteristics of recycled polyvinyl butyral

PVB-polyvinyl butyral, recycled	
Form	Flakes
Color	Colorless
Size	20–30 mm
Purity	More as 97%
Impurities	Less as 3%
Residual humidity	Ca. 2%
Contents of glass particles	Less as 2%
Fire point	–
Tg	130–170 °C
Viscosity (dynamic)	100–175 m Pa*s (DIN 53015)
MVR (melt volume rate)	6–7 cm^3/10 min
MFR (melt flow rate)	5–6 g/10 min

This recycled polyvinyl butyral was contaminated (dust, glass fragments), so it was necessary to thoroughly wash the material and dry it before starting laboratory work. By our research work we used PVB in the flakes form [9]. The recycled polyvinyl butyral used in the research has the following parameters (Table 4.1).

Granulate material is a more convenient and convenient alternative to the preparation of composite materials [10, 11, 15]. Polyvinyl butyral as thermoplastic material is soluble in ethanol, butanol, ethyl acetate, butylacetate, in a mixture of chlorinated hydrocarbons and insoluble in aliphatic hydrocarbons (in petrol). The density of the polyvinyl butyral used in the research was 1.07 $g.cm^{-3}$, and the recyclable price of the recyclate was 0.25–0.50 € per kilogram.

4.3 Laboratory Testing of the Recycled Polyvinyl Butyral

Before molding, the thermoplastic material was homogenized using a double screw machine. Continuous mixing was used to prepare the homogenized mixture. Homogenization of the material (Fig. 4.3) was carried out on a Brabender Plasti-Corder W 350 E. Laboratory investigations were performed at room temperature 22 ° C and 60% humidity. The use of molding technology from a comprehensive point of view is still today among the simplest and economically acceptable thermoplastic or thermoplastic processing technologies at all [12]. The pressing task is to form the molten polymer in the cavity of the die. In the case of the molding of samples formed by recycled polyvinyl butyral, the thermoplastic material was melted in the mold cavity and it has reached a melting point temperature (Tm) [4]. Continuous mixing was used to prepare the homogenized mixture. Continuous mixing provided complete homogenization of the material. Homogenization of the

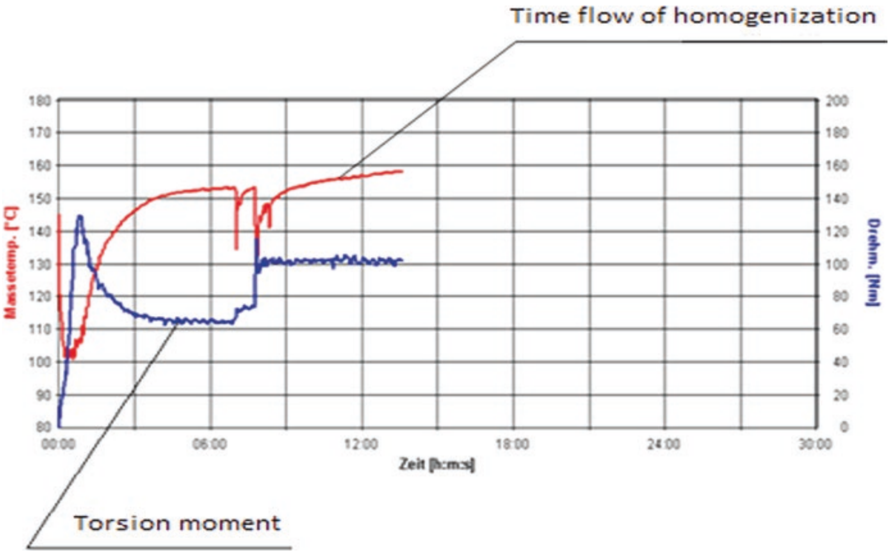

Fig. 4.4 Homogenization of recycled polyvinyl butyral by Brabender Plasti-Corder W 350 E [13]

material was carried out on a Brabender Plasti-Corder W 350 E (Fig. 4.4). Tests were performed at room temperature 22 ° C and 60% humidity [11]. The homogenization process lasted 15 min. At the time, the material was thoroughly mixed to prevent the formation of air bubbles that were undesirable in the molding process (resulting from compression, imperfect mixing, or incomplete filling of the thermoplastic mold cavity).

The homogenization process lasted 15 min. The material was thoroughly mixed and the formation of air bubbles that were undesirable during the molding process (occurring during compression, incomplete mixing, or incomplete filling of the thermoplastic mold cavity) was avoided. After homogenization of the recycled polyvinyl butyral on a Brabender Plasti-Corder W 350 E, the material was carefully selected and prepared for molding. The molding cycle [15] was composed of the following operations:

- Mold form opening,
- Filling the mold with a material,
- Closing the mold,
- Molding itself,
- Mold form opening,
- Selection of the mold,
- Cooling the mold,
- Cleaning the mold.

Table 4.2 Pressing conditions of the recycled polyvinyl butyral

Press equipment	Brabender W 350
Press temperature	190 °C
Pre-heating time	20 min
Pressing time	20 min
Cooling time	20 min
Pressure	10 MPa

4.3.1 Pressing of the Recycled Material

After homogenization of recycled polyvinyl butyral on a Brabender Plasti-Corder W 350 E, the material was carefully selected and ready to be pressed. Prior to molding, the mold was cleaned, minimizing impurities [13, 14]. The stamping was carried out on a laboratory press equipment Brabender W 350. The press cycle was composed of the following operations:

- Mold opening,
- Filling the mold with a material,
- Mold closure,
- Self-pressing,
- Mold opening,
- Removal of the mold,
- Cooling the mold,
- Cleaning the mold cavity.

Table 4.2 contains pressing conditions of the recycled polyvinyl butyral by Brabender W 350.

As mentioned above, after completion of the homogenization, test plates were pressed from which, according to DIN EN ISO 527-1, samples of type No.5 were pressed. Thus, the samples were prepared according to the standard, [15] they were ready for testing of mechanical properties of the material, by means of a tensile test. The tensile test (Fig. 4.5) evaluated the tensile strength of the material.

The test principle consisted of stressing the test body until the sample breaks. The test samples ware clamped into the jaws of the tensile test machine.

4.4 Conclusion

The work solved the recycled polyvinyl butyral film use again into production. Recycled PVB is an important component in the production of new materials, characterized by very good:

- Elasticity,
- Adhesion to various surfaces,
- Good water resistance.

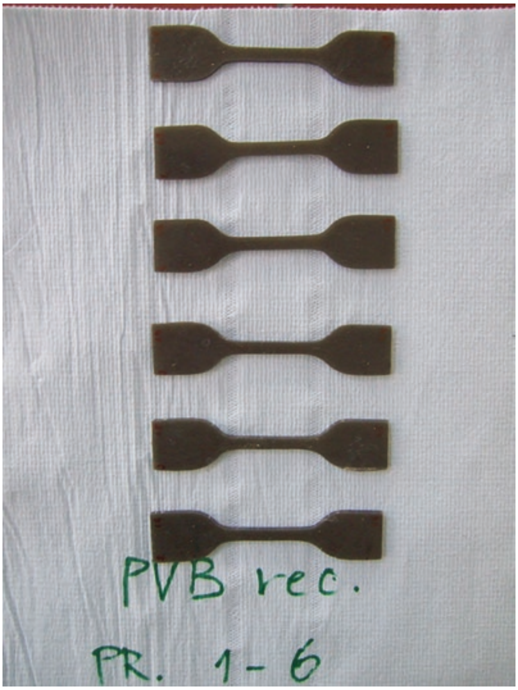

Fig. 4.5 Tensile test samples [13]

The advantage of the material is high compatibility with other polymers and also very good possibilities in the manufacture of composite materials. An important aspect of the processed issue was the

- Protection of the environment,
- The searching of environmentally acceptable ways of processing this commodity.

The application of materials was designed for the automotive and manufacturing industry. The use of materials from recycled polyvinyl butyral, especially composite materials based on recycled polyvinyl butyral, thus confirms the demand for these materials.

Realizing the processed problem, new application ways for material were found that can be used as a:

- Possible substitute for selected components of engineering production,
- Possible substitute for automotive production,
- Possible substitute for electro-technical production.

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Chapter 5
Cooling and Inflow System Changes in the Initial Phases of Plastic Injection Forms Construction and their Influence on the Mould Parts Deformations in the Simulation Process

Miroslav Maľcovský, Michal Balog, and Jozef Jurko

5.1 Introduction

The design, development, and the construction themselves are difficult processes, which based on the construction worker and the technology expert lead to achieving optimal and effective results of the construction process. The simulations which simplify and improve the construction are already important during the initiative phases of the component design – i.e. the design of the mould part constructed by injecting a plastic mould into a form. It starts with an idea, similar to any other project, and comes up to an expedition and a profit. What if the mould part does not correspond with the qualities expected? It is needed to remove all the defects, which can be prevented with a simulation.

Technological process and its result in the machinery industry is in some situations very much predictable in today's world. In the plastic mould injection process, a computer simulation is used and it can predict the defects in use of the given material and its behaviour already in the initiative phases of the form design. The primary role of each machinery construction company is to ensure a construction process of high quality. Keeping track of all the initial parameters entering the construction process from the beginning makes improvement and achieving high-quality results in the construction process much easier.

The purpose of the inflow system is to transport the melted plastic from the plasticisation chamber to the form cavity. The inflow force should be designed in a way

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to enforce the maximum pressure and equalise the volume contraction, i.e. to eliminate the pulled shape or the piping in the mould part.

5.2 Mould Part Construction Design

The mould part development and adjustment comes from the constructor's experiences. If the constructor feels like the mould part could be deformed compared to the designed geometry, it is needed to enlarge the ribbing or even make the walls heavier, so that there will not be a bending on the opposite site of the intake at the place where the material is being pushed into. According to the given mould part construction, the form constructor could adjust the form only by cooling or changing the intake placement. The intake placement is done during the development construction of the mould part. The placement and the enlargement of the intake make compression bigger. There are many options how to straighten the mould part and how to prevent the deformation. During the simulation, the constructor tries different scenarios, he changes the size and the number of the ribs, fills in the circumference, strengthens the bottom parts of the mould part, lightens the thin parts where there would flow more material, or there can be made a hole instead of the thick post where a screw would be inserted [1] (Fig. 5.1).

During the simulation of material flow, when the orientation of glass fibres changes from vertical flow into horizontal, the deformation of the mould part can be predicted according to the change in the flow direction. Thanks to the simulations of the material compression and the air bubbles creation, where the compressed air would over-heat, the form ventilation can be designed, so that the compressed air is ventilated from the form and the diesel effect would be prevented. Standard bending often occurs on several components. It can be disposed by adding a second intake or changing its position, so that its orientation would be identical with the flow orientation of the melt. Given modification can straighten the component. Parts with thick walls usually produce deformations due to material dragging and build-up. The

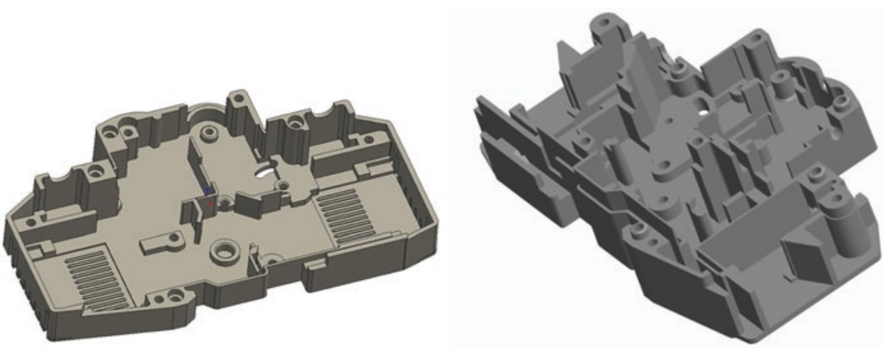


Fig. 5.1 Mould part construction design

simulation should be performed before the form to avoid possible problems that would not be possible to dispose of. It is all about the mould part development and construction while trying different ribs placement variations and other construction elements in different positions. The simulation can also be used to relieve the cycle when changing the input parameters.

5.2.1 Deformation Simulations

Many factors depend on the characteristics of the chosen material. During the simulation, material PA66 was used. Extruded material PA66 is known for higher thickness abrasion-resistance, compared to the basic PA6. Its mechanical characteristics are very similar to the material PA6G; however, the PA66 has higher perseverance and higher cost of acquisition [2] (Fig. 5.2).

Characteristics comparison with other materials:

Deformation analysis could theoretically point out how much the mould part deforms or bends, which can be eliminated by cooling improvement, for example. This analysis shows how of many hundredths or tenths of millimetre is the virtual value higher or lower than the real value. The simulation would show the bending but it cannot give the 100% accurate difference [4].

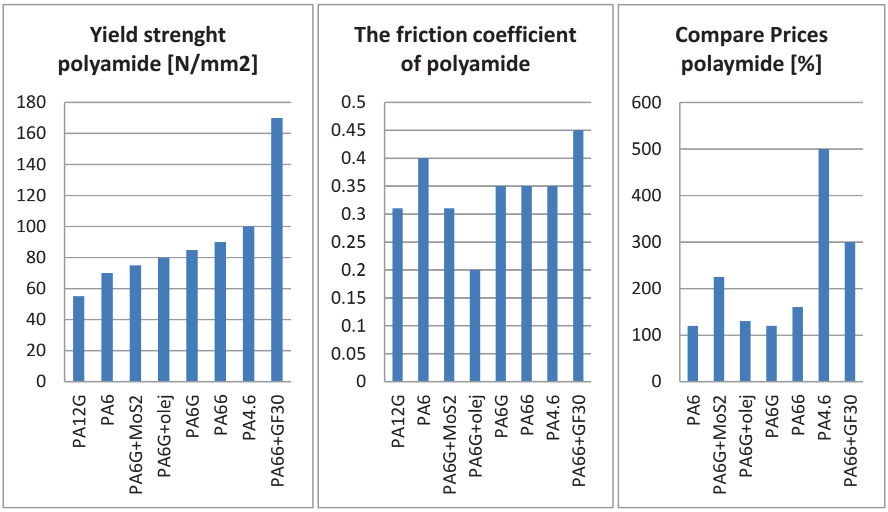


Fig. 5.2 PA6.6—Comparison materials [3]

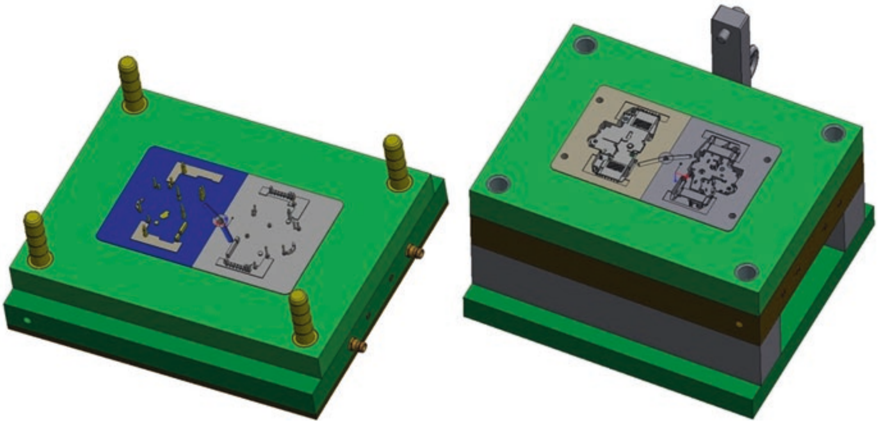


Fig. 5.3 Design of the form—construction

5.2.2 Construction Design of the Form

After the mould part simulation and the results analysis, it is appropriate to make also the cooling simulation with the construction design of the form. Different cooling canals average should be tried. The most important is to ensure even cooling on the whole circumference of the mould part [5] (Fig. 5.3).

From the point of the deformation, if we do not know the simulation and it would show 0.5 mm while we measure 0.3 mm, the form is designed correctly. To choose bigger or lesser evil when deciding from which point to bend the deformation could be appropriate. The so-called opposite bending to straighten the mould part is created.

5.3 Flow Simulation

The flow simulation offers a complete report in the form of videos and individual parts can show the advancing of the flow and thus the individual intakes or construction parts of the form can be changed to get precise results [6] (Fig. 5.4).

During the mould flow simulation, the original conditions as on the ARBURG injection moulding machine were created [2] (Table 5.1).

5.3.1 Pressure Drop

When the hollow is filled with the melt and compressed, the melt coagulates and diminishes in volume. The volume loss created needs to be refunded by inserting additional, small amount of the melt into the form. Pressure drop is one of

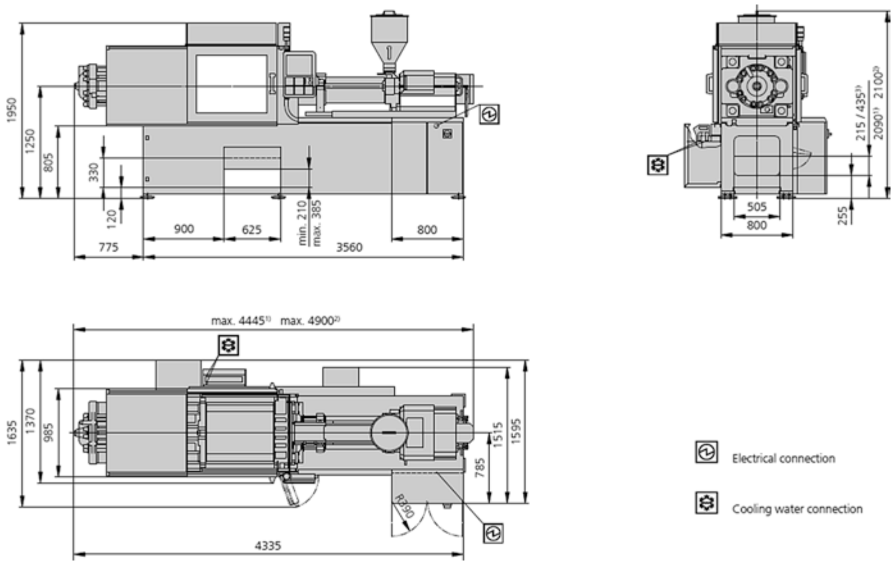


Fig. 5.4 ARBURG—injection moulding machine

Table 5.1 Injection moulding possibilities

Clamping unit	470 GOLDEN EDITION	Injection unit	400	800
With clamping force max. [kN]	1500	With screw diameter [mm]	40	50
Opening force/stroke max. [kN/mm]	350/500	Effective screw length [L/D]	20	20
Mould height, fixed min. [mm]	250	Screw stroke max. [mm]	160	200
Platen daylight fixed max. [mm]	750	Calculated stroke volume max. [cm3]	201	392
Distance between tie bars (w × h) [mm]	470 × 470	Shot weight max. [g PS]	184	359
Mould mounting platens (w × h) max. [mm]	650 × 650	Material throughput max. [kg/h PS]	29	53
Weight of movable mould half max. [kg]	800	Max. [kg/h PA6.6]	15	27
Ejector force/stroke max. [kN/mm]	40/175	Injection pressure max. [bar]	2000	2000
Dry cycle time EUROMAP min. [s - mm]	1,8–329	Holding pressure max. [bar]	2000	2000
		Injection flow max. [cm3/s]	168	214
		Screw circulferential speed max. [m/min]	53	60
		Screw torque max. [nm]	550	880
		Nozzle contact force/relation stroke max [kN/mm]	60/300	70/400
		Heating capacity/zones [kW]	9.4/5	19.9/8
		Feed hopper [l]	50	50

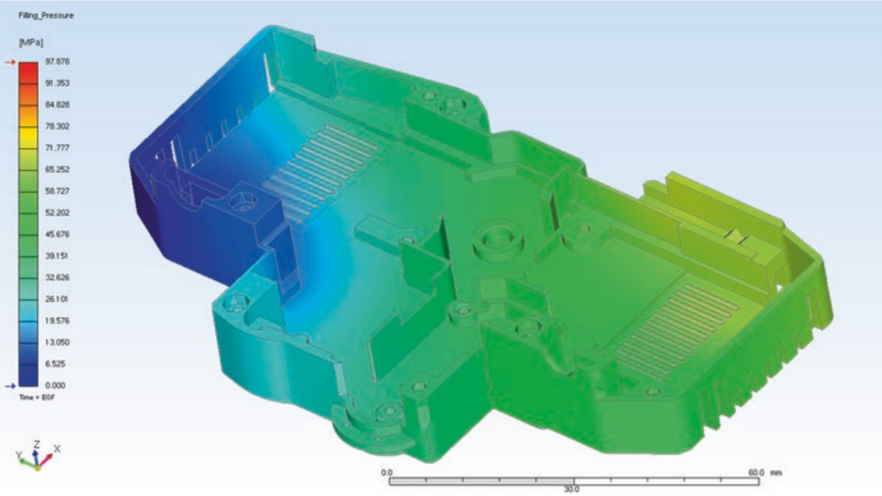


Fig. 5.5 Simulation—pressure drop

Table 5.2 Injection conditions

Injection pressure	110 MPa
Injection time	1.2 s
Melt temperature	290 °C
Pressure drop	75 MPa
Pressure drop time	2.15 s
Cooling time	25 s
Mould temperature	80 °C
Medium temperature	80 °C

the constants that greatly affect the inside case of injection, i.e. the structure of the product. The pressure drop amount and its duration need to be in accord with the melt cooling and its thickening. Pressure drop equals 40–60% of the mould injection pressure. The pressure drop is turned on when the form is filled for 95–98%. In the initial phase, right after the material compression, the pressure drop should be higher so that the form is filled with the additional small amount of material quickly, while the melt is still in liquid state. However, at the end the pressure drop needs to be lowered, which can be seen in the image with the colour scale [2] (Fig. 5.5 and Table 5.2).

5.3.2 *Weld Lines*

Weld lines occur in the situations when two flows join toghether, flows from two intake mouths meet, or when the thick and the thin parts of the component, caused by its unequal geometry, make the flows divide and then join in the form cavity.

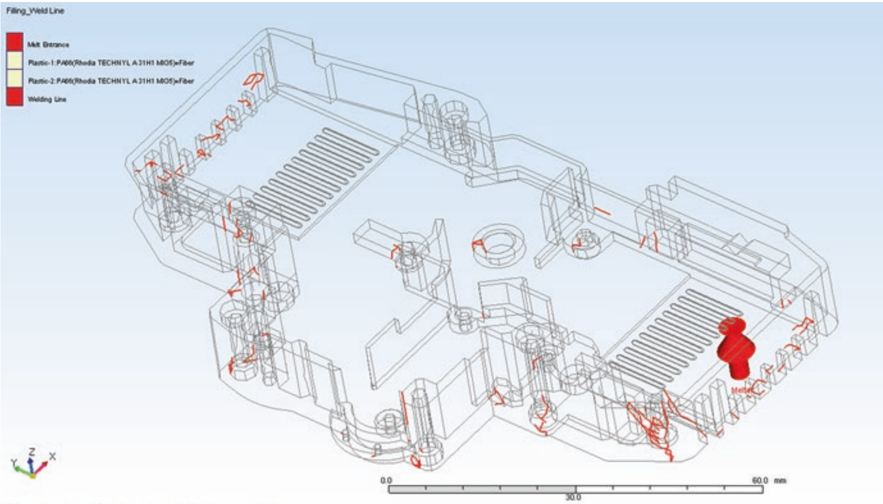


Fig. 5.6 Simulation—weld lines

It can look like an unnoticeable weld joint, a crease with rounded sides or, in the worst case, as a crack. Weld line is not only a visual mistake, but with the transparent plastics also an optical one. It can also weaken the component solidity for 10–20%, depending on its positioning. From the technological point of view, the solidity of weld line depends on the type of the plastic, the temperature of the melt, and the speed of the mould injection. There were weld lines found on the flow joints in the analysed product, however, they were not of considerable measures (Fig. 5.6).

5.3.3 Temperature at Flow Front

The melt flow orientation shows the way in which the melted material flows in the form hollow and whether this orientation is correct. The material flows from the intake mouth through the hollow to the other end, where the two flows join together. It is also visible on the time simulation. If the material does not have right flow orientation, the products could be unfinished. The orientation depends on the injection pressure and the speed, as well as the temperature of the melted material [7] (Fig. 5.7).

The dimension of the inlet system and the cooling system are important for simulation [2]:

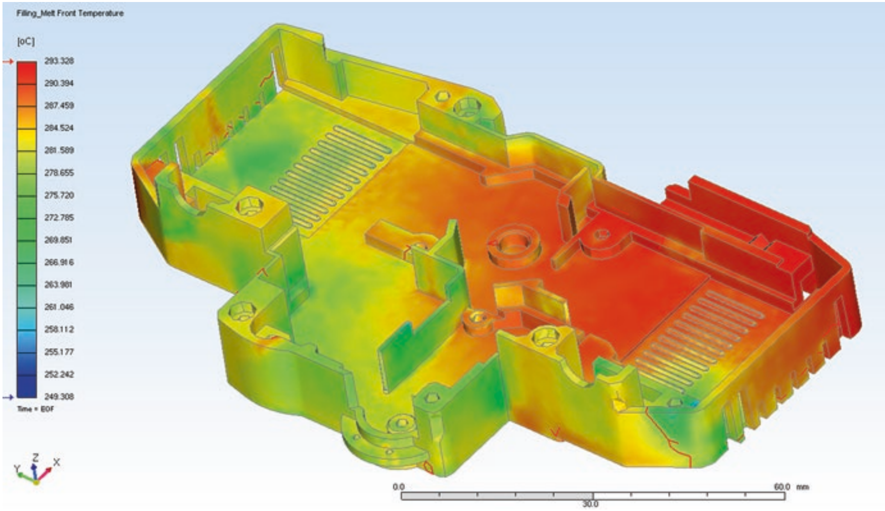


Fig. 5.7 Simulation—temperature at the flow front

5.4 Inflow and Cooling Systems

With the multiple forms, an appropriate gradation of the inflow canals needs to be kept. The precise diameter of the inflow can be insured only with the computer simulation analysis. However, in the real practice, in most of the cases this is possible with the experience and the basic theoretical knowledge [8].

It is necessary to keep the so-called cylindrical principle of the inflow shape (Fig. 5.8).

With multiple forms, an appropriate escalation of the individual inflow canals must be maintained. The correct choice of the inflow diameter can be made only with a computer simulation analysis. In practice, however, this is in most of the cases being made only with experience and the basic theoretical knowledge. The canals should be as short as possible, and, in the best case scenario, of an equal length for all the form cavities. This way, equal pressure conditions are created, which must be especially ensured with the mould parts of exact sizes. When it comes to small mould parts and higher forms of multiplications, large amount of waste material from the distribution canals is produced.

Looking at the costs of forms, moulding, and the amount of materials, it is important to take into consideration using the warm inflow system [8].

The warm inflow systems, used when desired by a client, are more costly compared to the cold ones; however, they shorten the injection cycle and allow an automated production. With the multiple forms, distribution blocks are used. Depending on the cavities placement, there is a different jet arrangement with own temperature regulation of each block (Fig. 5.9).

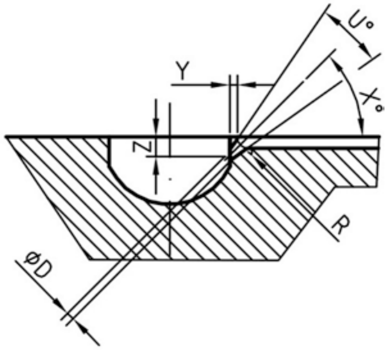


Fig. 5.8 Cylindrical principe of the inflow shape. U ° - Inlet cone angle; X ° - Inlet angle; Ø - Inlet diameter; R - the radius of the rounding of the inlet; Z - Inlet Depth; Y - Distance from shape

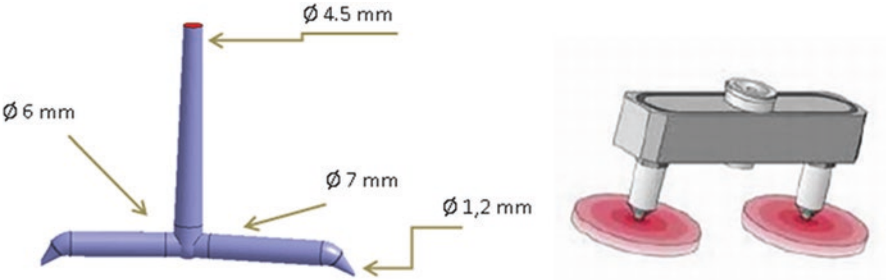


Fig. 5.9 Cold inlet system/Hot inlet system [8, 9]

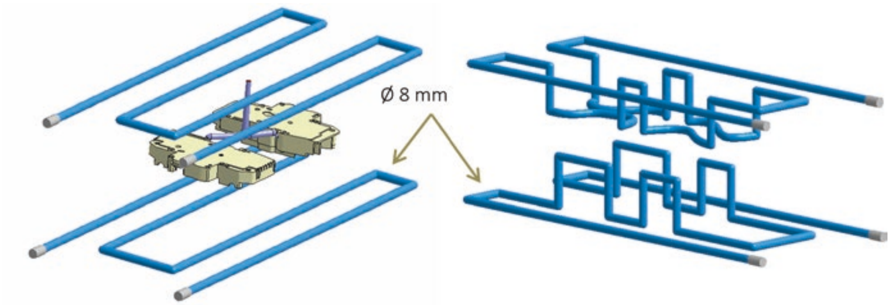


Fig. 5.10 Original cooling system and new cooling system

The canals should be as short as possible, ideally of the same length for all the form cavities so that identical pressure conditions are created, which is needed to be followed especially when in production of mould parts identical in size (Fig. 5.10).

The organisation and dimensioning of the cooling system inside of the form highly influences the characteristics of the injection, it's deformation, cooling time and placing the form into the cycle. Currently, there is an immerse number of different plastic parts, shapes and materials used, thus the exact theoretical and construction data for a correct form tempering does not exist. Usually, it is the experience of the designer who is preparing the given system, which is crucial. However, the other factors creating a compromise with the functional aspects of the form, such as the shape and the positioning of the ejector, the shaping inlay, the adjustable parts, etc. also need to be taken into consideration [8] (Fig. 5.11).

The chosen cooling system should, in the first place, match the requirements of the equal cooling time of the melt along the shape intersection. This is today enabled by the Mould Flow or the Cadmould Cool simulation. This correctly designed cooling system ensures the minimal surface deformation of the mould part (Fig. 5.12).

New cooling system has reduced the surface temperature by 6099 °C less but deformation is still occurring.

Using the classic inflow system and then performing a simulation, it was found that the filling is uneven. In the highlighted area, the mould front is slowed down due to the big change in the wall thickness (Fig. 5.13).

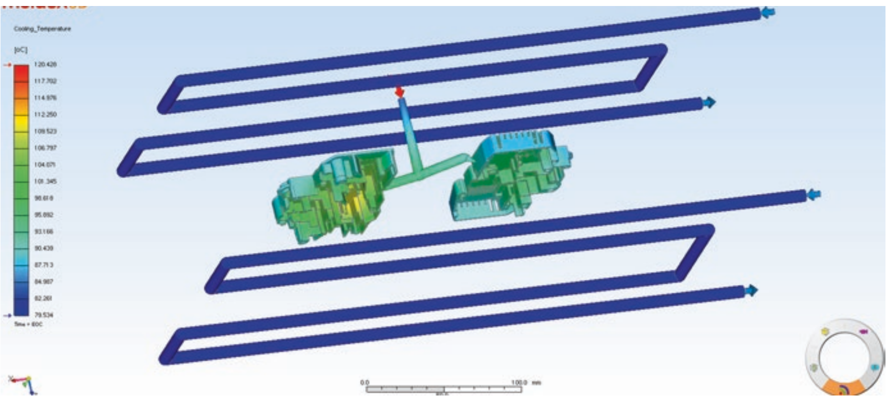


Fig. 5.11 Simulation—cooling temperature 120,428 °C

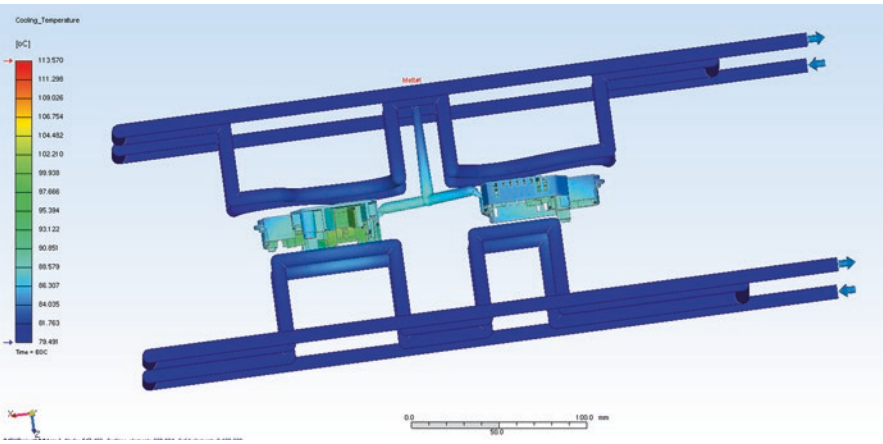


Fig. 5.12 Simulation—Cooling temperature 113,570 °C

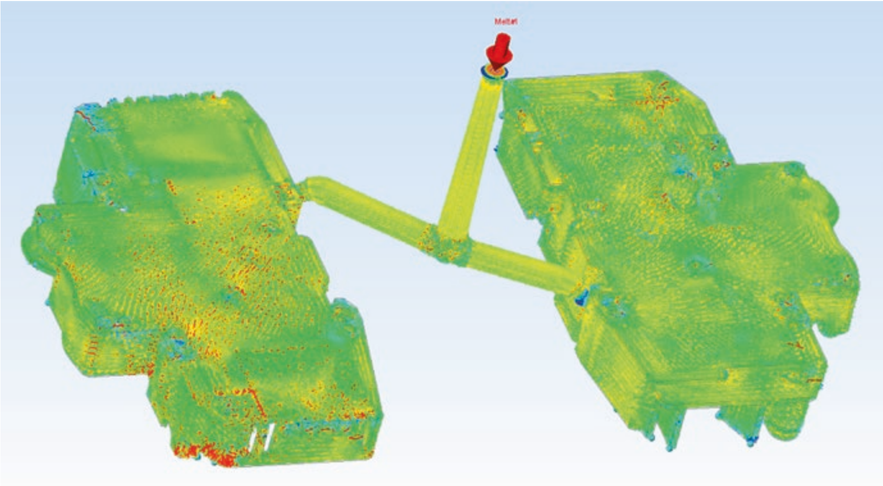


Fig. 5.13 Uneven filling of the material

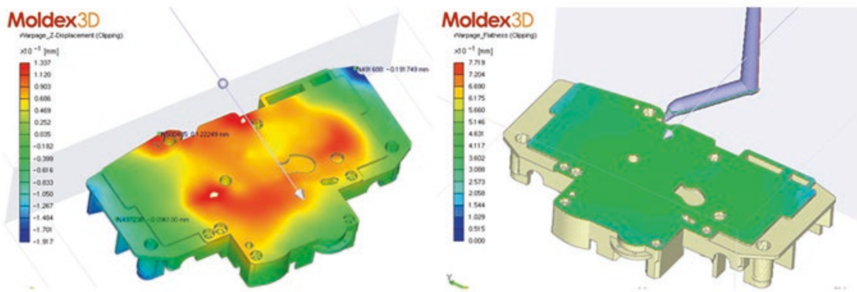


Fig. 5.14 Flatness and deformation in Z-axis direction—cold inlet

In the deformation simulation of a cold inflow, the part is bending in the axis "Z" direction of 0.71 mm and the flatness at the measured area using the hot inflow is 0.55 mm. (Fig. 5.14).

Using the hot inflow, the part is bending in the axis "Z" direction of 0.3847 mm and the flatness at the measured area is 0.1467 mm (Fig. 5.15).

5.4.1 Advantages and Disadvantages of the Hot Inflow

One of the biggest disadvantages is a complicated construction of the injection form.

Among the advantages are:

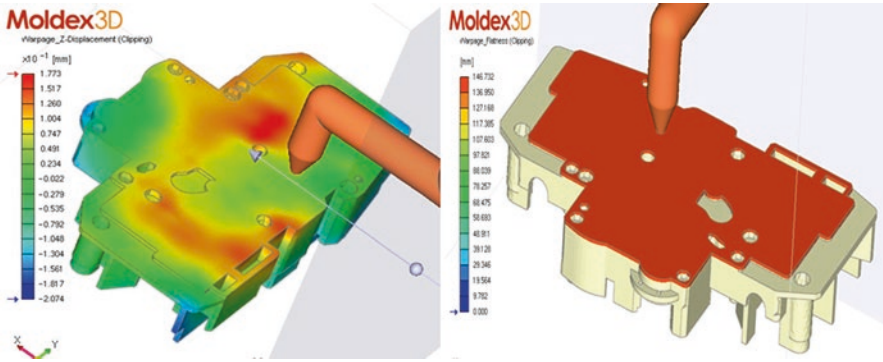


Fig. 5.15 Flatness and deformation in the Z-axis direction—hot inlet

Table 5.3 Deformation results

Deformation Z-axis	Cavity 1 (mm)	Cavity 2 (mm)
Original cooling system	0.654	0.710
New cooling system	0.658	0.675
Hot inflow	0.3847	0.3847

Deformation - Flatness	Cavity 1	Cavity 2
Original cooling system	0.55	0.60
New cooling system	0.58	0.55
Hot inflow	0.1467	0.1467

– Higher quality of the plastic parts.
– Shorter injection cycle time.
– Ensuring equal viscosity during the full time of the flow.
– Higher quality of the injection pressure.
– Reduction of the injected material volume.

The inflow system does not harden; therefore, it is unnecessary to deal with its separation and recycling [10, 11] (Table 5.3, Fig. 5.16 and Graph 5.1).

The results of the comparison of deformations:

5.5 Conclusion

Reducing the surface temperature of the part does not influence the deformation. The deformation could be reduced by changing the input parameters.

Using the hot inflow system, there is no hardening of the injected material. Smaller deformation in the axis "Z" direction is happening, together with a smaller deformation of flattening. The injection cycle is shorter, thus the filling of the parts

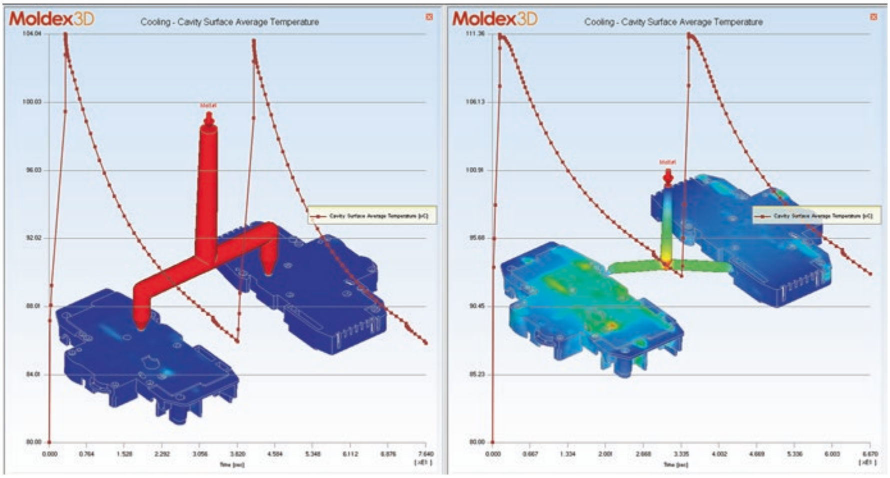
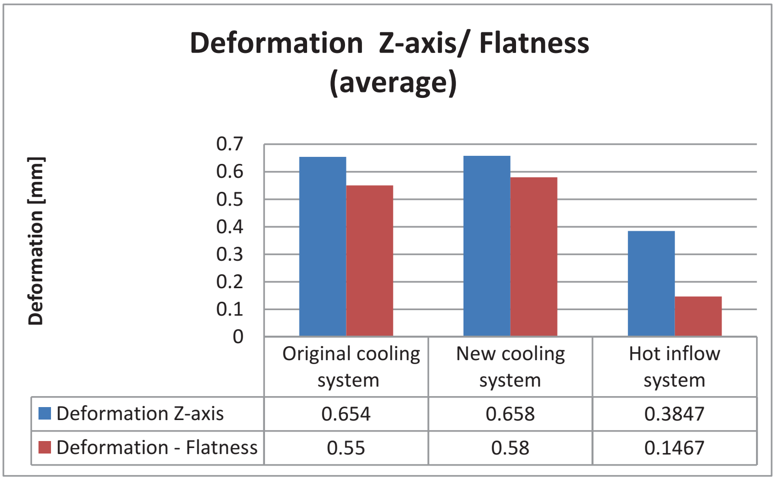


Fig. 5.16 Cooling—Cavity surface average temperature



	Original cooling system	New cooling system	Hot inflow system
Deformation Z-axis	0.654	0.658	0.3847
Deformation - Flatness	0.55	0.58	0.1467

Graph 5.1 Graph of deformation results

is equal and the parts surface quality is better. This definitely brings higher costs of hot jet; however, the quality and the size of the deformations achieved by the inflow system change during simulations, needs to be taken into consideration.

The simulation process can, in many cases, ease the debugging and verification of the chosen construction, technology, and the whole construction process. The cooling usually needs to be done in the best way possible since every businessman wants the shortest production time possible. The cycle shortens with a better cooling, thus the mould part can be delivered to the customer sooner. A change in the cooling, for example, adding or changing the position of the cooling canal causes changes in the deformations. The difference in temperatures during a balanced cooling at 5 °C is within the tolerance range. During the simulation, the temperature of the form and of the material can be changed. If there is a problem with the injection, the simulation of the temperature change from 80 to 90 °C brings better results of the mould part behaviour. Many things are given with the mould part construction, which are in the end the initial phases of the process, where simulations are needed to remove defects and fasten the production.

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Chapter 6
Material Selection and the Designed Measurement Stand

Zuzana Murčinková and Michal Halapi

6.1 Introduction

In an industrial environment, it is essential for manufacturing companies to innovate and improve quality. This gives them a competitive advantage and differentiation of the market. Last but not least, the manufacturing company needs to develop and implement the above-mentioned innovations and quality, as well as employees who are able to manage and implement these changes at the proper level.

One option for innovations is to introduce new or innovative products and technologies. At present, product design in pre-production stages is increasingly influenced by new materials and new production technologies that have been considered progressive and are currently being successful and want to become conventional. New features for the production of components are 3D printing (plastics, metals) and rapid prototyping.

In the field of new materials, the composite materials start to be increasingly used, especially laminates being mostly used for the availability of inputs and hand layup technology of production. It is supported by existing modules for laminates in commercial software for numerical analysis in pre-production stages. Other new materials include various auxiliary materials, porous structures, hybrid materials, etc. Often, the components combine different materials and therefore different bolding–jointing possibilities are developed. Moreover, new materials and new technologies enable the development of various non-traditional component shapes.

The production layout for the mechanical engineering production (semi-finished products, CNC machines, production logistics) intended for manufacturing of the

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conventional materials (steel, alloys, copper, cast iron) is principally different from the production layout for production of composite material components. The principles of creating a conventional and "composite" workplace are diametrically different in terms of control, maintenance, testing, prevention, etc.

In area of planning and management of pre-production stages and production itself, the sophisticated approaches are used in different levels of information systems to the arrangement of processes so that the manufacturing system can flexibly respond to impulses.

The European Commission in co-operation with EFFRA (European Factories of the Future Research Association) outlined the changes expected in the manufacturing sector in the coming years [1]. As a result of many workshops and strategic discussions within the European stakeholders from manufacturing industries and the related research community, it has been determined that the successful development of high added value technology should consider the following strategic sub-domains:

- Sustainable manufacturing.
- Information and Communication Technologies (ICT) enabled intelligent manufacturing.
- High performance manufacturing.
- Exploiting new materials through manufacturing.

New materials bring new challenges in sustainable manufacturing that require new approaches for low resource consuming processes and process intensification, integrated with hybrid processes, as well as knowledge-based processes exploiting advanced modelling and simulation techniques.

6.1.1 Material Selection

The products must fulfil functionality requirements, it means the product must work properly, be safe, and economical. It is the main aim of technical design. The technical design and industrial design form together the product design. The market and individual industries need the materials lighter, stiffer, stronger, tougher, cheaper, tolerant of temperature extremes and environment [2]. The adopted products involving the new and advanced materials and processes are the result of the change pressure. Moreover, there are the science, research, and development forces that discover new or advanced materials (superconductors, nuclear materials) without direct influence of market. Aluminium was a scientific wonder at the beginning of nineteenth century, similarly as the steel at the beginning of twentieth century. Nowadays, the composite materials, bio-materials, functionally graded materials, nanostructured materials, smart materials, etc. give the potential of new design.

In [3, 4], the aim of materials selection is described as the identification of materials, which after appropriate manufacturing operations, will have the dimensions, shape, and properties necessary for the product or component to demonstrate its required function at the lowest cost.

The steps in the material selection process according to [5] are as follows:

- Understanding and determining the requirements.
- Selection of possible materials.
- Determination of candidate materials.
- Testing and evaluation.

6.1.2 Approaches to Determine the Dynamical Properties of Composite Materials

The chapter and field of research is from a very recent area of new and advanced materials and their mechanical, especially dynamic, properties.

To determine the mechanical properties of composite materials is not trivial task. At present, such properties are determined by analytical, numerical, and experimental approach. The basic analytical approaches are mentioned in [6]. The numerical approaches are still developing regarding the suitable and reliable numerical method [7–11] overcoming the problems of numerical analysis (more in [12]). The mechanical properties as natural frequency, natural shapes, time of damping, etc. can be determined also experimentally [13]. This chaper is contribution to experimental determination of mechanical properties of composites by development of the measurement stand that will be the part of the measuring chain.

6.2 The Measurement Stand in Material Selection Role

The data obtained by the measurement stand are intended to be utilized in upper mentioned stage (step) of Determination of Candidate Materials to complete the material property information especially in field of dynamic properties as natural frequency, time of damping, damping coefficient, energy absorption, etc. Materials data enters at various stages of the design process, but the level of accuracy required on material property information differs at each stage [5]. In the initial stage of the design process (conceptual stage), approximate data for wide range of materials is gathered and design options are kept open. This information can be helpful in the preliminary assessment of these materials. In the preliminary stage, a designer identifies which matrix material and fibres are more suitable [5].

After selecting the candidate materials for the various types of feasible manufacturing processes, prototype parts are made and then tested to validate the design in Testing and Evaluation stage [5]. The measurement stand is useful even in that stage of material selection.

In generally, to analyse the modal properties of production machines, equipment, materials the bump test with modal hammer is used (more in [14]). Combination of the proposed measurement stand supplemented by vibrometer can partially substitute such equipment. Moreover, the accuracy and reliability of measuring and measurement stand was the main goal since the accuracy of measurement depends mainly on the quality of the measuring apparatus and the skill of the scientists taking the measurement and *reliability* is the degree to which an assessment tool produces stable and consistent results [15].

6.2.1 Individual Parts of Stand and their Function

To develop model of the measurement stand (Fig. 6.1), the software Autodesk Inventor Professional 2016 was used. To determine the natural frequencies and shapes of specimens, it is needful to apply the impact force. The modal hammer is usually used to apply impact force and determine mentioned properties. In this case, the impact ball with specific parameters is used. The ball rolls on the inclined groove. The ball impacts the specimen by specific velocity applying the specific impact force that can be calculated by analytical form.

The proposed design of the measurement stand defines a position-adjustable measurement stand. Priority has been proposed for the research (testing, measurement) of behaviour of composite materials—natural frequencies and shapes. However, it is designed to be usable for other types of materials to be subjected to such measurement. When designing the stand, consideration was given not only to the variety of

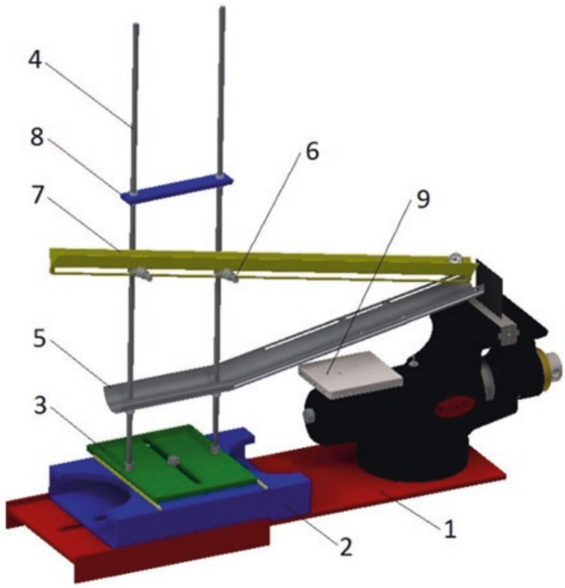

Fig. 6.1 3D model of the measurement stand, (1) base plate, (2) longitudinal table, (3) cross table, (4) threaded bars, (5) outlet of impact balls, (6) adjusting screws, (7) impact ball runner, (8) fixator, (9) clamp

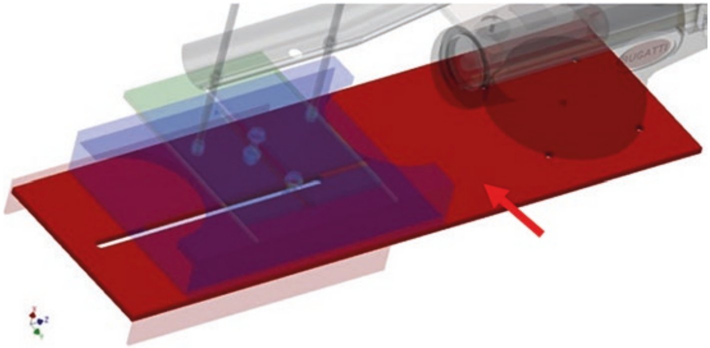

Fig. 6.2 3D model of base plate

materials but also to the shape and size of the specimens to be measured. Except to classic flat rectangular specimen shapes and rotating shapes up to a diameter of 125 mm, it is possible to measure essentially any shape of the specimen if it is possible to clamp it in the measurement stand. Stand is of rigid construction but with the ability to adjust the various positions needed for measurement purposes.

The base plate 1 (Fig. 6.2) is from E295 of thickness 12 mm. In the middle is the groove for adjusting screw. The groove is of 16 mm width and 400 mm length. It is sufficient for large range of table motion. The sides are welded to base plate on the lower part so as the welds do not interfere with moving the longitudinal plate. The sides are also the limiting slides for longitudinal table. At the opposite end of base plate, there are the holes for fixing the clamp.

The longitudinal table 2 (Fig. 6.3) enables change of distance in direction of measuring. It is a welded structure consisting of plates of different thicknesses. This table has two grooves, one is on the lower side and the second one is on the upper side. They are perpendicular. The longitudinal table is by lower groove mounted to the base plate. The screw joint prevents mutual movement. The semi-circular cut outs allow easier manipulation with screw joints. Moreover, the sides are welded to longitudinal table to allow movement perpendicularly to direction of measuring. The groove is of 16 mm width and 260 mm length.

The cross table 3 (Fig. 6.4) provides the motion perpendicular to measuring direction. The screw is in groove and it allows to fix the table in set position. The special nuts are welded to this cross table to be able to fix the guide threaded bars. These bars are locked by contra-nut to avoid the spontaneous unlocking.

The guide threaded bars 4 are used for the precise adjust of inclined impact ball runner by use of other special holders which are moving along these bars.

The outlet of impact balls 5 (Fig. 6.5) is the part of structure to avoid secondary excitation by repeated impact into structure (measurement stand). The shape and dimensions of outlet are designed regardless the shape and dimensions of impact body. Of course, its position must be adjusted so that it does not touch the specimen or any other part where the specimen is placed.

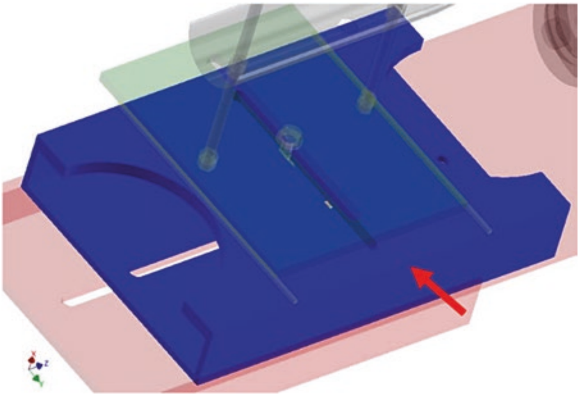

Fig. 6.3 3D model of longitudinal table

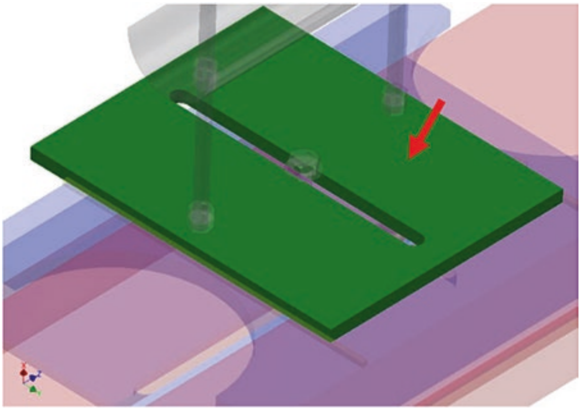

Fig. 6.4 3D model of cross table

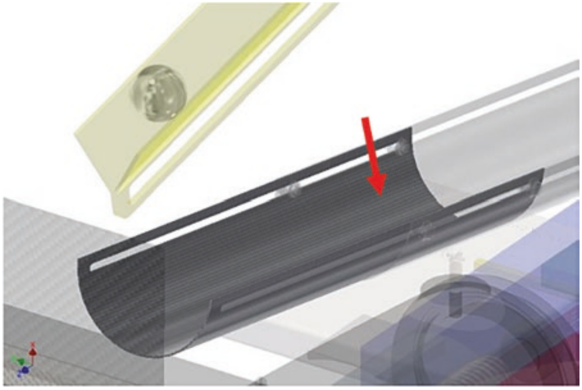

Fig. 6.5 3D model of outlet of impact balls and ball runner

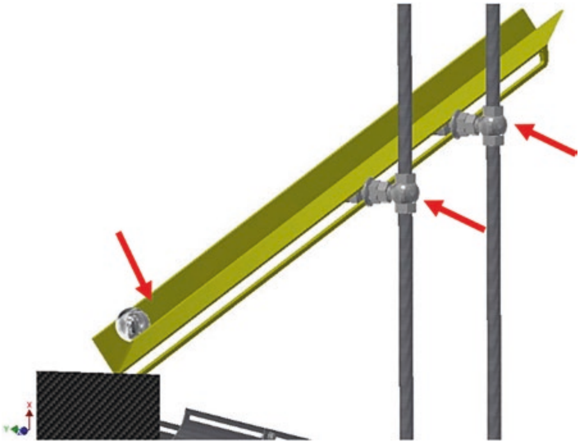

Fig. 6.6 3D model of adjustable screws and ball runner

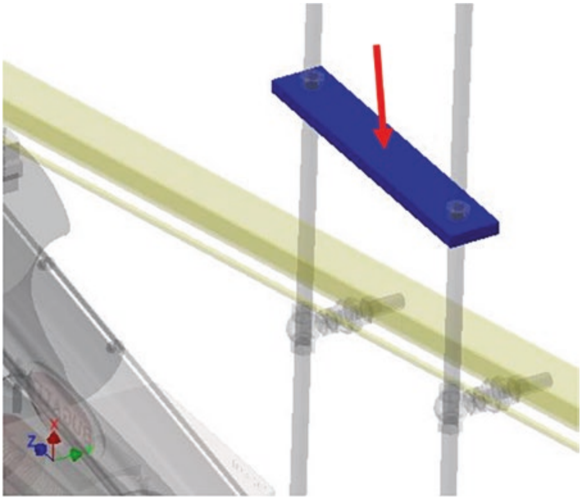

Fig. 6.7 3D model of fixator of threaded bars

The adjusting screws 6 (Fig. 6.6) are special holders that can be moved along threaded bars. Their position is locked by nuts on the both sides to avoid unwanted vibrations and spontaneous displacement as a result of impact ball movement.

The impact ball runner 7 (Figs. 6.5 and 6.6) is mounted on the special holders using the pair of nuts on each side. The runner has shape of regular L-profile so that the contact of impact ball and runner is minimal. The shape of the runner also allows to use various types and dimensions of impact bodies. The runner is 1 m long which can provide a wide range of impact force. The runner also has a ruler for adjusting the distance of the impact body from the specimen, which is another factor influencing the magnitude of the impact force and thus the excitation.

Fixator 8 (Fig. 6.7) serves to insure the mutual position of the threaded rods but regarding their length of 1 m, the additional insurance was necessary because they tended to change their mutual position or oscillate. This fixator is also moving along the rods and fixed by a pair of nuts on each of them.

The clamp 9 is multifunctional in order to be able to hold the square flat specimens. It is equipped with flat jaws and for the rotation specimens the possibility of snapping into the prism, or a combination of these attachments. The clamp has a 125 mm the clamping range and it can also rotate about 360° about an axis perpendicular to the base plate.

The impact body can be balls of different diameters, weights, and material. The ideal choice is sphere (ball) impact body because of the lowest possible friction, as the ball touches the regular L-profile at two points. The tested specimens can be of various shapes (flat, rotational) up to 125 mm of clamp maximum jaw expansion.

6.2.2 Some Results - Natural Frequency and Damping Time

Some of results of measuring are provided in Figs. 6.8 and 6.9. Figure 6.8 involves also images of specimens of three-layered laminates consist of the glass (IG) (Fig. 6.8, up) and the carbon (C) (Fig. 6.8, down) fibre twill fabric, respectively. The specimen layers are oriented the same way. The boundary conditions of experiment for both types of specimens are same.

The results correspond with material properties of glass and carbon. Graph in Fig. 6.8 confirms the better damping properties of carbon fibre specimen. Moreover, the first natural frequency (Fig. 6.9) of carbon fibre laminate is higher (compared to glass fibre laminate) due to its higher specific modulus of elasticity (Young modulus/density).

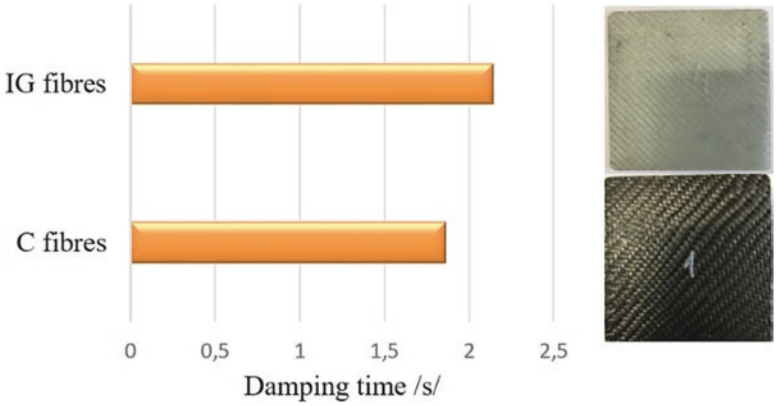

Fig. 6.8 Damping time and specimens – laminate with IG (up) and C (down) fibres

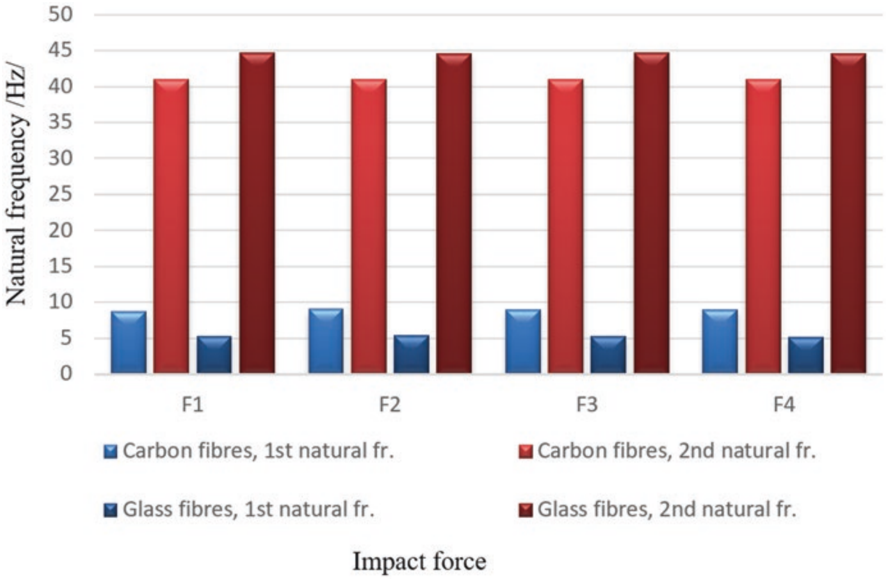

Fig. 6.9 Natural frequency of specimen laminates (F1-F4 are different values of impact force)

6.3 Conclusions

The presented stand is a support for material selection process to obtain specific material data in pre-production stage of identification of potential material and its testing and evaluation.

The proposed measurement stand is a part of the measurement chain to evaluate the dynamical properties of the composites—specimens or specific components. It contributes to experimental approach that can be linked to the analytic as a comparison or as a combination with analytical and/or numerical approaches. One of the advantages is that the measurements are repeatable with the same parameters of impact force thus the measuring errors are minimized. The measuring stand is designed to be universal for various composite materials and different shapes and dimensions of the specimens, materials, and parts.

Thousands of material choices are available to an engineer to assist in right material selection. This reveals the need for an expert system for the selection of alternative materials for a given application [5].

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Chapter 7
Internet of Things Concept for Informing Visually Impaired Persons in Smart Factory Environments

Dragan Peraković, Marko Periša, Ivan Cvitić, and Petra Zorić

7.1 Introduction

Previous research in the area of indoor navigation and information of the visually impaired users is based solely on the possibilities of using ICT technology such as AIDC (Automatic Identification and Data Capture). For the purpose of informing users, various possibilities of assistive technologies are often used, in which the most important are mobile devices and devices adapted to provide various sound information. Most of the previous research does not exclude the use of the white cane as basic tool for informing the user, but rather it is being upgraded to various forms of assistive technology, such as the application of various sensor devices [1, 2]. Using VLC (Visible Light Communication) technology, it is also possible to transmit data, so some research is focused on exploiting LED technology for indoor user informing [3, 4]. With the development of technology and the ever-increasing of new smart solutions application, a concept of new ICT technologies application in indoor environments, such as AAL (Ambient Assisted Living), is created. The basic prerequisite for the development of new services based on the AAL concept is the use of sensors in the IoT (Internet of Things) environment. Research in the field of IoT concept application in indoors are different, from the possibility of providing user assistance to informing systems in the Smart Home environment [5, 6]. In indoor environments, it is also possible to inform users by using a mobile camera and integrating it into the WSN (wireless sensor network) [5, 7, 8]. It is also possible to inform users about the environment and objects surrounding it by using various sensors [7]. Indoor environment includes factory environment and production where

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one of the workers in them are visually impaired persons. One of the key objectives in the field of encouraging the employment of the persons with disability in the European Disability Strategy 2010–2020 is to ensure increasing of persons with disability on the labor market and to ensure better accessibility on workplaces [9]. By developing the concept of Industry 4.0 factory, manufacturing processes is also gaining a new dimension where most of the processes are based on contemporary ICT solutions [10]. The processes of designing information systems for process management in production requires well-elaborated user requirements in order for the company to cope with all challenges of the current development of the Industry 4.0 concept [11]. In order to develop Industry 4.0 and the EU guidelines for the implementation persons with disabilities (visually impaired persons) in production processes (Smart Factory), the conceptual system architecture to design information service is proposed in the chapter. The goal of service for informing users (visually impaired persons) is to facilitate work in a smart factory environment and to fulfill aspects of the users' quality of life. The lack of all mentioned researches is clearly defining user requirements that are the basis for the development of new services in the area of providing real-time information for the indoor moving users. In this chapter, based on collected information on user needs, the user requirements are defined for the delivery of indoor user informing services in smart factory environments. This chapter is a follow-up of the research on sensor technology (IoT) use for users informing [12–14].

7.2 Defining User Requirements in Working Place

For the purpose of designing functionalities and guidelines for the development of user informing services, it is necessary to define their requirements for indoor informing. Content and features of informing services must meet all elements of the UD (universal design) in addition to user requirements. It is also important to consider work environment where the user is located and additional upgrade of the service functionality.

7.2.1 User Requirements Research

For the purpose of defining user requirements, a research was conducted among people with damaged vision in which group belongs the blind and visually impaired person. In the city of Zagreb (Republic of Croatia), according to currently available data, 1971 persons with vision impairment belong to persons with severe vision damages (both eyes 411) and those with a certain degree of visual impairments [15]. The research was conducted in collaboration with the Up2Date association (which has 60 active members and 30 volunteers) on a sample of 81 users, of which blind persons were 40%, visually impaired 23%, and other disability rates 37% (Fig. 7.1).

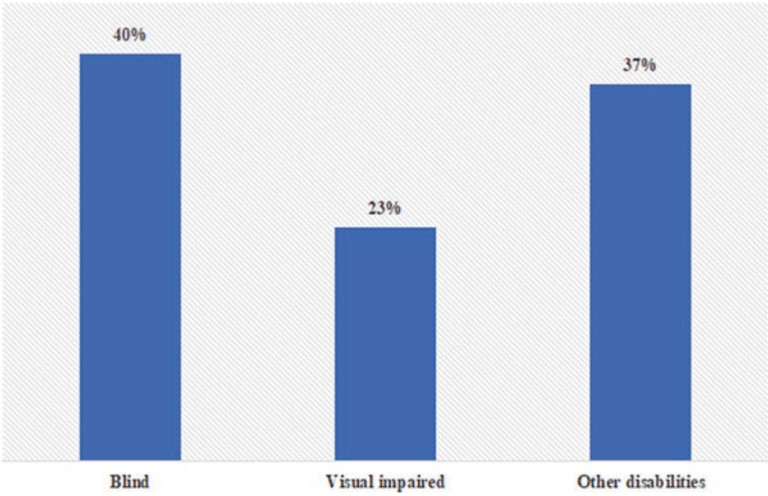

Fig. 7.1 Type of user's disabilities in research

When moving independently (without a guide or assistant) in indoor spaces users are faced with many challenges, such as locating the requested object, navigating indoors, finding an exit in an emergency and getting information of user environment. Currently, the most common way of informing users indoors is the tactile line of guidance (bank, public, and other institutions).

Information about indoor facilities that surround the users and notification about their presence is considered important to 86% of users. Information on possible obstacles (work on movement routes, benches, decorative elements, trash bins, etc.) that can be found in motion is considered very important and important to 78% of users. A user who moves independently has difficulties in identifying objects and obstacles, thereby further endanger the safety of movement. Intendent movement is associated with determining the user location, and 83% of users consider informing about their location important and very important.

In the indoor space, personal belongings can often be lost where the user with visual impairment can have difficulties to notice the loss of a particular item (money, wallet, other personal items), and 51% of users would like to be informed about such a situation.

Everyday activities, which includes users' indoor movement, requires additional physical effort for the user if he is in the new and previously not described place. New services whose basic functionality would be to inform the user about the environment and the possible notification on the following activities would raise the degree of user mobility. Users are interested in introducing new services (87%) designed to meet user requirements and UD elements. According to the obtained data, 93% of users use a smartphone for daily communication. For the purposes of introducing new informing services, users have the desire to receive the requested information through the devices seen in Fig. 7.2 (32% is mobile application installed

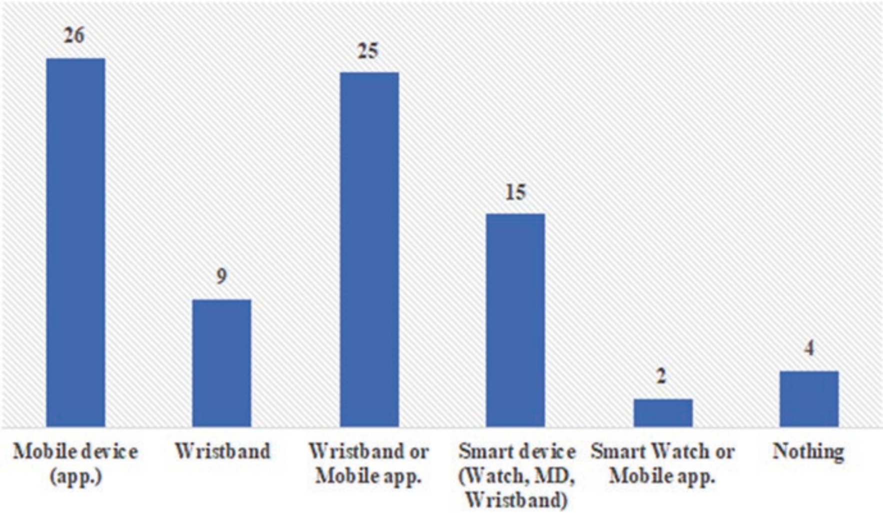

Fig. 7.2 Possible ways of informing users

on user's mobile device). A number of users chose more options, where is also seen the presence of mobile device and associated applications.

7.2.2 Defining Service Functionality and User Requirements

The design of the system required for providing indoor user informing service can be based on the AAL/ELE (Enhanced Living Environment) platform. After identification of the AAL/ELE-based facility, basic requirements of the concepts have been defined [16]:

- Open—the system should allow enhancements to the new and already existing technologies. It should allow internetworking of the heterogeneous segments on a single platform.
- Virtualized—the system should be virtual at different levels in order to allow better administration and service development.
- Generic—the system needs to be as generic as possible. This means that the services should not be specific but more natural for the end-users.
- Scalable—the system should be scalable and should be capable of being installed in very small scale and be expandable to the large scale at later stage.
- Module-based—the system should be proposed in modules that are interoperable and could map, merge, split, and interact using standard interfaces and protocols.
- Customizable—the system should be as customizable as possible. Based on the generic nature of the initial set of functions the end-users and stakeholders should

be capable of changing configuration in order to serve their personal preferences, peculiarities, local customs, religion specific requirements, etc.
- Granular—the system should work at different levels of granularity allowing the end-user to change it.
- Security and privacy should be included in all layers and components of the system.

Based on the current research in the IoT technology application field and collected data on user needs in this research, the following customer requirements are defined [17]:

- The possibility of using service on the smart device.
- Obtaining all relevant information about the environment.
- Real-time informing.
- Using TTS (Text to Speech) option.

Based on user and basic requirements, guidelines for development and functionalities of indoor user informing service are defined. The development guidelines can be divided into two categories:

- **Content customization** must be enabled for all levels of visual impairment such as increased content fonts allowing the ability to work with TTS options and content in multiple contrast colors.
- **Ease of use** according to UD principles needs to meet the following areas:
  - Ensure equal means of use for all users.
  - Usage flexibility.
  - Mode of use choosing (left or right handed).
  - Simple and intuitive use.
  - Perceptual information.
  - Low level of physical effort.

The functionality of user informing service in indoor environment should have the following capabilities:

- **Informing users about possible barriers:** It is defined as the real-time information about all the relevant obstacles (e.g., benches, garbage bins, storage boxes, ornamental plants, and the other) on the user's route.
- **Notification on nearby objects:** It defines all the spaces for which the user has expressed interest. When using this functionality, it is necessary to allow enough time for the user to decide on further movement direction.
- **A short description of each facility**: According to UD recommendations, it is required to provide the user a simple description of each objects.
- **Item description:** An item is considered any subject of business in a facility. By informing the user on an item it is possible to create an imaginary image of what user is purchasing or has a desire to purchase.
- **Simple registration of lost things:** Functionality that can raise a feel of person's safety when moving.

- **Information on accidents:** Information that enable safe routing to emergency exits.
- **Workers tasks**: It defines business tasks in the production environment.

The functionality of user informing service will be based on the proposed system architecture and technologies: Beacon BLE, Fog, CC (Cloud Computing), and sensors, which will ensure the delivery reliability of all the requested information to the end-user.

7.3 Analysis of Information Delivery Technologies

Delivering data and information from the user's environment that is moving through indoor environment can be based on AIDC technologies, sensors, VLC technology, and Beacon transmitters. Table 7.1 shows the advantages and disadvantages of an individual technology for the purpose of delivering data and information from the environment of the user moving indoors [12, 18].

According to data obtained by analyzing the capabilities of technology, the optimum data an information delivery technology is Bluetooth BLE, Beacon technology. Bluetooth technology is an open standard applicable in the IoT and AAL/ELE concept. The technology allows communication between the Beacon transmitter, the user's mobile device (MD), and the defined databases located in the Fog or CC environment.

The distance at which Beacon transmitters can communicate is 10 [m] when the transmitting power is 1 [mW], and when the transmitting power is increased, it is possible to reach up to 100 [m] in perfect conditions. In realistic conditions, the maximum range at which this technology is used is 30 [m], making this technology the most convenient for indoor use. With the correct configuration of the Beacon transmitter it is possible to send data from different distances, whereby three parameters of distance are defined:

- Immediate, up to few centimeters,
- Near, up to few meters,
- Far, above 10 meters.

Depending on the real conditions in which the Beacon transmitters are placed indoors, the signal may change its value, which can cause problems when determining the exact location. The capabilities Beacon transmitters have in the indoor environment are:

- Launching the application on MD when Beacon signal is identified.
- Send feedback in the form of a push message.
- User guidance and routing using the Beacon transmitter map.
- Ability to work on iOS devices, with iBeacon communication protocol.
- Eco-mode (power and message sending interval reduction) can extend battery autonomy.

Table 7.1 Possibilities of using ICT in indoor environments

Technology type	Advantages	Disadvantages
RFID	1. Tag price. 2. Passive tags do not have additional power.	1. The ability to remove a tag from the object. 2. Implementation with multiple devices that compromise UD. 3. Inability to work for all the above-mentioned service functionality. 4. Components maintenance.
NFC	Tag price	1. The ability to remove a tag from the object. 2. Implementation with multiple devices that compromise UD. 3. Inability to work for all of the above-mentioned service functionality. 4. Requires close proximity to a device and great user effort for locating.
AIDC Barkod, QR	Tag price	1. The ability to remove a tag from the object. 2. Type of information storage. 3. Inability to work for all of the above-mentioned service functionality. 4. Requires close proximity to a device and great user effort for locating.
VLC	1. Using and utilizing LED technology. 2. Resistance to the congestion caused by the increasing use of WiFi technology. 3. Easy to locate a user using a mobile device, smartphone.	1. Limited range and outage caused by reduced amount of light. 2. It is exclusively used for data transfer and not for storage.
Camera optics	The ability to use the camera on a smartphone	1. Implementation with multiple devices that compromise UD. 2. Inability to work for all of the above-mentioned service functionality.
Beacon BLE Bluetooth	1. The ability to provide real-time information. 2. The ability to work with all mobile devices OS. 3. Work with all the above-mentioned service functionalities.	1. Price of Beacon device. 2. Battery autonomy.

From AIDC technology group, optimum technologies for using are RFID and NFC. For the purpose of identifying user and monitoring his work activities, it is possible to use NFC technology. Apart from the identification with Beacon transmitters, objects in the environment, if it is a smart warehouse environment, can also be identified by using an RFID tag [14].

7.4 Conceptual System Architecture Proposal

For the purpose of delivering the information to the user in the indoor environment, this chapter proposes system architecture based on the Fog/CC platform applicable in the smart factory, shown in Fig. 7.3. Mentioned platform enables the system operation in the IoT environment and according to the AAL/ELE concepts with the aim of delivering real-time information to the end-user. It also enables interaction and participation of all stakeholders important for creating information.

The conceptual system architecture is based on the information and communication solution SA for A, where Beacon transmitters also use the data collected from the sensors [13, 19, 20].

The mentioned Fog / CC platform is applied indoors where the Fog node is based on a private or public CC service using client—server and peer-to-peer architecture. The user's terminal device can connect to the Fog node via the Radio Access Network (RAN) network or WiFi network. The interaction between all levels of Fog/CC depends on the service-level agreement (SLA) that needs to be sufficient for providing an adequate service level [16].

Proposed architecture also features Fog 2 Fog (F2F) and Fog 2 Cloud (F2C) communication enabling, checking, and verifying data. Sensors used in the smart

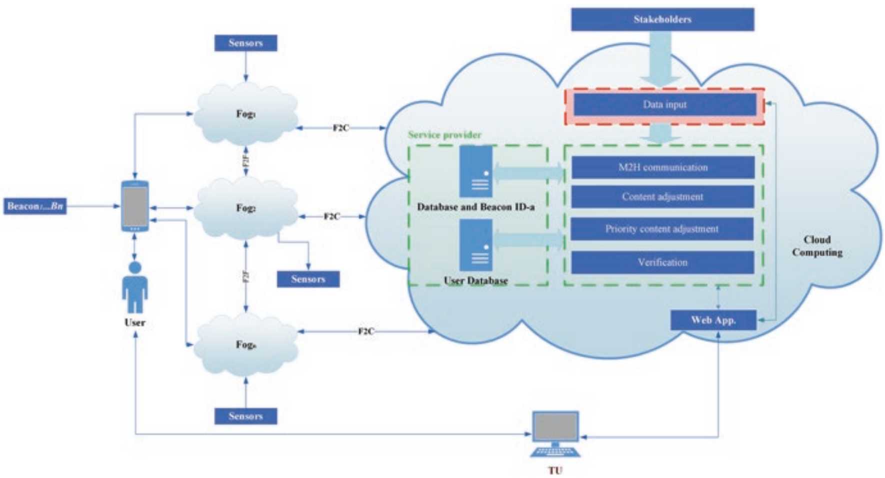

Fig. 7.3 Conceptual system architecture

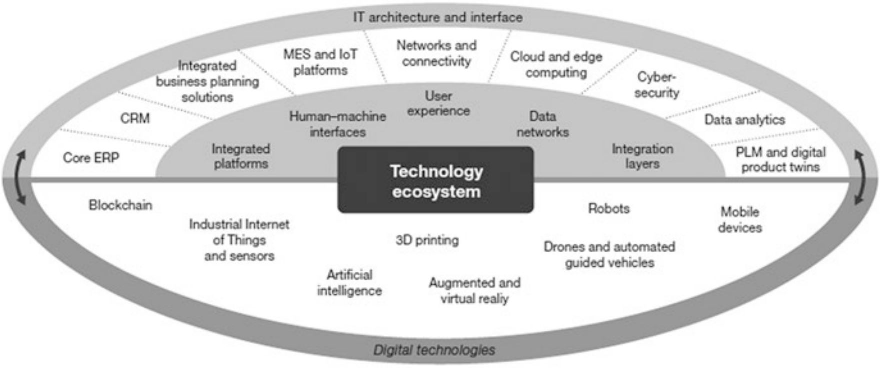

Fig. 7.4 Overview of Technology in Industry 4.0, [22]

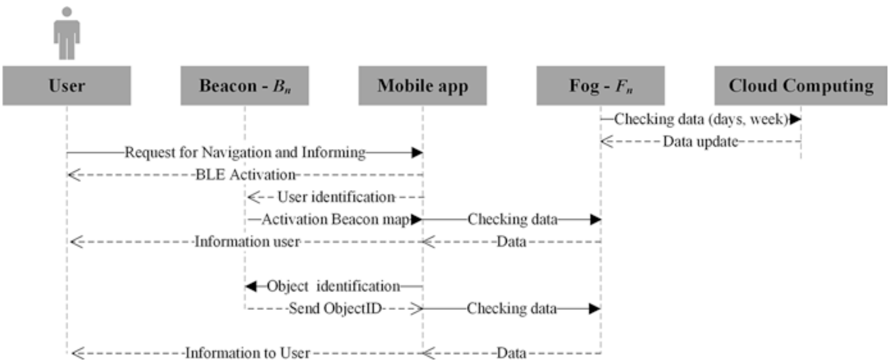

Fig. 7.5 Process of objects identification and informing users in smart factory

factory environment are: temperature, humidity, fire detection, object detection, movement and monitoring of goods, specific sensors (in case of such an environment and they are further defined), stock management, shelves and rows location, specific gases and others. The work of the proposed architecture is also based on concept of Industry 4.0 technologies as shown in Fig. 7.4.

An example of user identification and informing service delivery using conceptual system architecture in smart factory environment is shown in Fig. 7.5.

When using a Beacon transmitter, the user must activate the BLE signal on his MD. Upon identifying the user's MD, the Beacon transmitter (Bn) triggers an application installed on the user's MD, after which a check is performed with the Fog node. Fog node will return a defined database record (according to a specific ID from the Beacon transmitter) to the mobile application, based on which information is created for the end-user. Using Fog technology enables faster delivery of real-time information (measured in milliseconds) that do not require further processing, analysis, and forwarding. With Fog technology, higher reliability and lower latency are expected.

Fog nodes also have elements such as database, user base, and Beacon transmitter base from CC architecture seen in Fig. 7.3. Fog to CC Communication is executed at precisely defined time intervals and can be expressed in days, weeks, months, depending on system requirements. In order to allow additional information creation and network access for all stakeholder groups (associations, public institution, crisis management systems, navigation maps service providers, and others), it is envisaged to establish the system according to the PaaS (Platform as a Service) model.

When entering, each data is adapted to M2H (Machine-to-Human) communication in a form acceptable depending on the user's degree of disability. M2H communication also enables the adaptation of the information according to the Braille line [21].

All data required for Beacon transmitters (Beacon transmitters base) is stored in the database. Based on stored data, all the information needed to inform the end-user are created. The user database, which contains user account information and their settings, is in the CC architecture section that belongs to the service provider. The user database provides the information necessary for verification and customization of the content according to the user's priority. Content customization is based on user characteristics and functionality chosen by individual users.

The users access their data through a mobile application on a mobile device or via a Web application using an Internet browser. The Web application is used exclusively to define the user profile and to view the availability of the Beacon transmitter.

Comparing Beacon and GPS technology, GPS can route the user to a specific facility where further routing and information can be made by using a Beacon transmitter. Using NFC technology, the user must be close to the tag itself and activate the NFC reader on his MD if it is integrated (not all devices have NFC readers). In indoor environment, it is recommended to use Beacon transmitters on the WiFi network. The reason for this is a check that takes place with the Fog node where it is possible to achieve faster data transmission compared to the 3G/4G network usage. It is also possible to use closed IoT networks such as: Sigfox, Industrial Wireless Networks (IWN), Zigbee, LoRa te LoRaWAN.

7.5 Proposed Conceptual Architecture Testing

Arduino Uno Development Environment, Raspberry Pi3, and Computer Server (part of CC environment) were used to test the proposed system architecture. Testing and monitoring were carried out in the Laboratory of Development and Research of Information and Communication Assistive Technology at the Faculty of Transport and Traffic Sciences. The goal of testing is simulation of the proposed system architecture and overview of the ability to collect, process, and deliver information to the end-user.

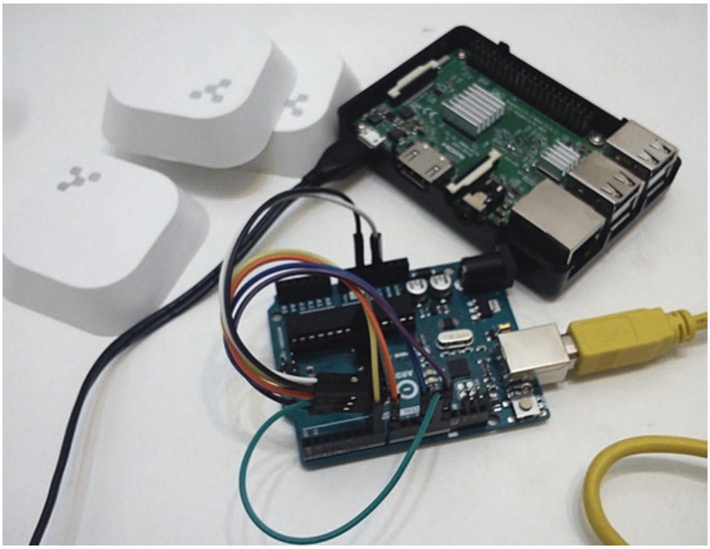

Fig. 7.6 Arduino and RPi3 components for testing

Operation monitoring equipment used in this research is as follows (Fig. 7.6):

- Arduino UNO.
- Raspberry Pi 3 (2 pcs).
- HC-05 Bluetooth module.
- Kontakt.io Smart Beacon (3 pcs).

In the work simulation, the Arduino UNO component represents MD, one Raspberry Pi3 (RPi) represents Fog, and another RPi represents CC environment. Beacon transmitters used in testing are Smart Beacon (ToughBeacon) based on Eddystone format for development of the iBeacon application. The serial protocol was used for communication with the HC-05 module.

Three Beacon transmitters were used in the testing, one was used for initialization while others were used as location for Beacon transmitters. Each Beacon transmitter has its own MAC address, the Arduino Uno component reads the specified address after which the BeaconID is sent to the Fog node. The Fog node searches the BeaconID in its database that consists only of the data of a objects, with the purpose of faster processing of CC requests. This database contains information related to the local area in which the user is located. When the Fog node receives the BeaconID that is not in its database, it forwards the query to the CC. There are large amounts of data in the CC that require extra processing to extend the functionality of location-based services whereby the BeaconID is related to that data (e.g., objects or elements of smart factory). In addition, the CC in its database contains additional information about objects related to BeaconID. The CC can also include a location in the facility, e.g., where an item can be found and forward the user instructions to that part of the facility.

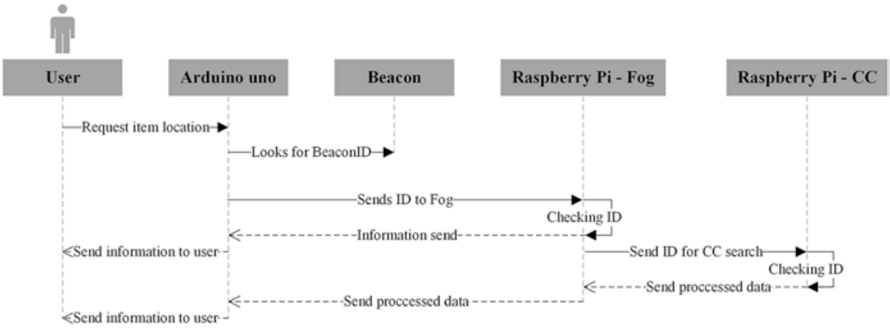

Fig. 7.7 Information flow of simulation measurement

In this book chapter an overview of the simulation results is presented. Simulation was conducted regarding the possible scenario of the proposed architecture's application in the IoT environment. Application scenario refers to warehouse management with items within a smart factory. Based on presented simulation results it is possible to check the status of individual items within a certain row in the warehouse. This information is related to one of the Beacon transmitters in the area called the initialization Beacon transmitter. Application for guiding and informing users on his MD receives information of item location and inform the user. Such information as well as basic information about the location on which the item or user is located is obtained from the Fog node. The information flow in the carried-out simulation is shown in Fig. 7.7.

Figure 7.8 shows the Fog node simulated on the RPi3 device. When receiving ID from initialization Beacon, Fog is checking for any specific services available only at that location, such as specific item that is on discount (marked in the red box).

If the check is positive, such information is sent back to the MD with the basic information. If there are no additional services, the Fog node will only forward basic location information. When receiving an ID that is not in its database, Fog node sends a query to CC (connection marked in blue frame) that performs additional processing of its database records. After processing the data CC transmits the expanded information to Fog node which then forwards it to the end-user (marked in green frame). The Fig. 7.8 shows information about the item mass, volume, and the expiration date.

7.6 Security Features of Smart Factory Environment

Implementation of new information and communication concepts such as IoT, CC, and Fog Computing into conventional factories and manufacturing processes results in significant changes in the direction of increased efficiency and performance. The increase of the application above-mentioned concepts is accompanied by increase

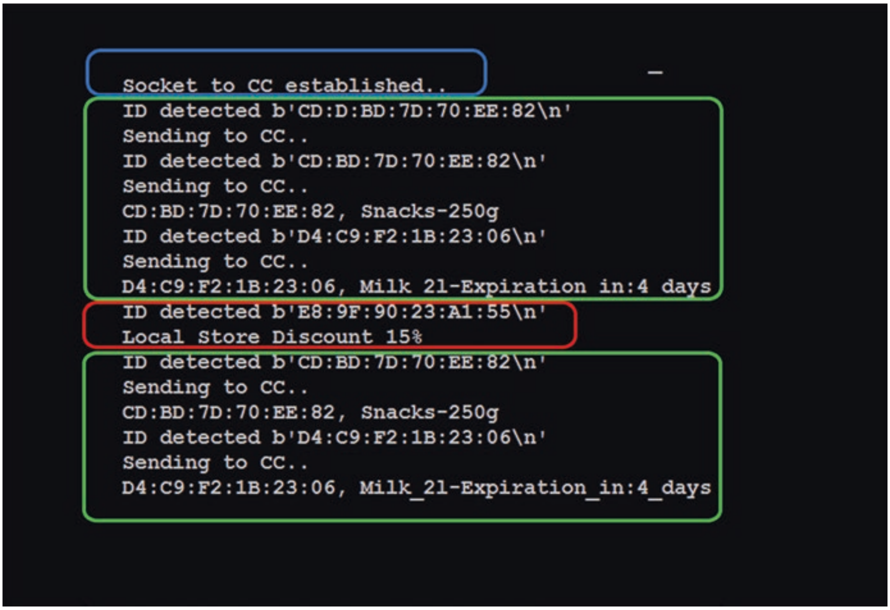

Fig. 7.8 Simulation of data verification in the Fog/CC environment

of cyber security challenges and need for adequate and forehand detection of vulnerabilities whose unauthorized exploitation can have negative consequences on the overall system [23].

By integrating visually impaired persons into a smart factory environment, preventing unauthorized changes, reading or deleting data becomes even more important since inaccurate or undue information delivery can cause a large number of user work errors or endanger users life [24]. Therefore, a holistic approach to the security of smart factory environment is necessary, which implies protection of all information and communication concepts and technologies involved in delivering information to the user with visual impairment.

Since the architecture of the system proposed by this chapter is based on the concepts of Cloud and Fog Computing and Beacon BLE technology, these elements will be further observed from the aspect of security.

7.6.1 Security Aspects of the Cloud Computing Concept

CC as a concept is often used in the IoT environment in general for the purpose of processing large amount of data collected by sensors and ensuring availability of these data regardless of location. Due to rapid development and high acceptance rate, this concept possesses numerous vulnerabilities that can be exploited unauthorized [25]. One of the recognizable vulnerabilities are associated with virtualization and multiple lease. These are also key components of above-mentioned concept and they provide the ability to modify and create malicious virtual machines by unauthorized users [26]. In addition, research identifies the most common vulnerabilities in the CC concept [27]:

- data leakage,
- availability of services,
- insufficiently strong cryptography,
- reliance on access to the Internet network.

According to the above-mentioned vulnerabilities, during the implementation of CC concept, it is necessary to ensure the achievement of standard security goals (confidentiality, integrity, and availability). This implies the implementation of strong encryption algorithms and their application in communication, fulfillment of industry security standards such as PCI-DSS. Also, the application of system for detection intrusion on network level but also at the hypervisor level is required. This will enable supervision and traffic control exchanged between virtual machines on the same physical server [27].

7.6.2 Security Aspects of the Fog Computing Concept

The Fog Computing concept has been developed to fulfill the emerging needs of processing an increasing amount of data generated in IoT environment. Fog provides decentralization and unloading CC servers, reduces response time, and increases resources availability required for data processing [28]. Despite many benefits it offers in IoT environment, Fog has certain vulnerabilities that need to be considered during its implementation and application. Research identified potential problems and vulnerabilities in the Fog Computing application [29]. Fog succeeded certain security issues from CC concept such as virtualization vulnerabilities and the ability of numerous web-based attacks such as SQL injection, cross-site scripting, session or user account stealing, and others.

Fog also provides advantages from the aspect of data security delivered to the user. As can be seen from the conceptual architecture of the system shown in Fig. 7.3, Fog nodes are in intercommunication, continuously exchange data and create redundancy. This may be of importance in the case of compromising Fog node. In this case, it is possible to validate data in the observed node and identify unauthorized modifications or deletions of data on time. Above mentioned is of importance in forehand and accurate delivery of information to the system user.

7.6.3 Security Aspect of IoT Devices

Terminal devices in the IoT concept are most often sensors, actuators, and identification devices. Each of these devices has specific functionality and purpose such as data collection, data receiving or storage, and transmitting of identification information. For the purpose of sending/receiving data, IoT devices are equipped with communication technologies. The proposed architecture used Beacon that transmits identification information using Bluetooth BLE technology. IoT devices itself, and used communication technologies, have vulnerabilities that is necessary to pay attention. Some of the vulnerabilities are [30–32]:

- Physical characteristics of the device: Perceptual layer devices are small dimensions (sensors, actuators, identification tags, etc.) that result in installation of hardware components even smaller dimensions (CPU, RAM, ROM, communication interfaces) where characteristics of these components are often limited.
- The price of the device: Specificity of the perceptual layer devices is their quantity. Sensors, actuators, and identification tags are used in large quantities to create relevant IoT environment and to gain valuable data. Therefore, the price of the device must be low and to achieve profitability, the cost of the components installed in the devices must be low which again leads to large limitations in the implementation of protection methods.
- Energy characteristics: Devices of this layer must have a high autonomy which implies a small energy consumption. Such characteristics are negatively reflected on the traffic security that is generated and exchanged through such devices.
- Implementing security methods: All above-mentioned results in the inability implementation of powerful data protection methods such as strong cryptographic algorithms due to hardware limitations (RAM, CPU, traffic bandwidth, traffic management capabilities, etc.).

Bluetooth as a wireless communication technology is vulnerable to threats such as traffic monitoring, signal bandwidth expansion, disabling communications, intercepting communications, and exchange of data transmission. Considering the Beacon device location in the smart factory environment and the limited signal bandwidth of Bluetooth technology, it is important to physically and technically protect the object where such devices are in order to disable unauthorized persons entry who would physically have access to Beacons. It is also necessary to periodically check the devices functionality for forehand detection of physical damage and its replacement, as well as for checking the accuracy of the information the device is transmitting.

7.7 Conclusion

Increasing user mobility and the ability of its active participation in the work environment is the goal of proposed service for informing in indoor environments. Using Beacons and appropriate sensors technology in Internet of Things concept and in the Fog/Cloud environment, real-time information can be delivered to user in a reliable and secure way. Using the Fog concept allows faster response of the system itself for the purpose of delivering information, while CC architecture performs data collection, processing, and analysis. Fog will deliver only data that do not require further analysis and processing as demonstrated by testing of the proposed system architecture operation. By designing services according to guidelines and defined functionalities, it is possible for a user to have a simpler functioning in performing their daily activities without using a special assistant. Such form of information and communication technology utilization also represents application of assistive technology model in indoor environments and users work environment. Industry 4.0 concept provides the ability to implement contemporary forms of assistive technology to help specific groups of users in the work environment.

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Chapter 8
Manufacturing Precision of the CNC Milling Machine with Three Controlled Axes

Jozef Svetlík, Juraj Kováč, Patrícia Dudová, Jozef Dobránsky, and Michal Považan

8.1 Introduction

This chapter gives a detailed example of modeling machine precision in order to familiarize the scientists with some research results on the possible enhancement of working accuracy of machine tools at the stage of their virtual prototyping. The identification of the effects of the machining process itself as well as the impact of machine design features will allow it to predict and subsequently optimize its construction in terms of its working accuracy. The practical importance of virtual machining is primarily the reduction of financial costs and acceleration of machine design without the need to produce a physical prototype. Using simulation models, it is possible to repeatedly analyze the weak spots of the machine design to determine the effects of each machine component on its properties and to optimize them, but also to take account of ergonomic and other requirements. In the publication of the mentioned virtual machining methodology and the corresponding simulation models, two basic types of machine tools were developed—for machines for machining rotary parts (turning machines with horizontal axis of spindle) and machines, respectively, machining centers for machining non-rotating workpieces of small to medium dimensions.

In general, it can be stated that it is highly unlikely for a field of human activity to exist completely unrelated to production technology, where the dominant position

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is apparently occupied by machine tools. Machine tools are involved (whether directly or indirectly) in the production of virtually any product, so their improvement, streamlining, increasing the quality of production, and the ability to respond flexibly to customer requirements are essential.

Machine tool manufacturers are constantly working to reduce the time and cost needed to launch a new machine tool on the market. Considerable time savings can be achieved at the development stage of the new machine by gradually eliminating the need to manufacture its prototype, and by verifying the properties of newly engineered machine through simulation models. This principle of the so-called virtual prototyping is already commonly used, for example, in the aviation and automotive industry and is supported by the existence of powerful hardware, but equally so by perfect software products.

Computational design support for machine tools through analyses utilizing the finite element method is now a common part of their development process. Standard structure-related calculations are those of their static, dynamic (modal analysis), and thermal properties. However, requirements for the level of sophistication of machine tool structures are constantly on the rise. The market demands solutions that reduce production times and make the production process more efficient as a whole, while increasing the machining precision of workpieces. High-Speed Cutting applications are highly dynamic processes to which the concept and design of machines must be tailored accordingly.

Standard computational simulation methods no longer suffice to successfully meet all of the requirements for the construction of advanced-level machines. Behavior simulation of the mechanical part of the machine design must be considered, taking into account the processes directly related to the operation of the machine and significantly affecting its properties and achievable machining precision. At the EMO-global trade fairs for machine tools, a number of computational simulation solutions have been recorded over the years in all of the above-listed areas.

The production and testing of the physical prototype of any technical object is both time consuming and costly. Therefore, it is necessary to intensify the research, development, verification, and practical implementation of various rapid prototyping methods. One of the possibilities is virtual prototyping of machine tools based on the principle of virtual machining, which tests the properties of the proposed technical work on its mathematical models.

The use of computer support is a common process when designing machine tools using CAD programs with the possibility to use FEM analysis. The ever-increasing demands on the design of machine tools and machining processes, HSC machining requires not only standard calculations of dynamic, static, and thermal properties, but it is necessary to deeper and take into account the processes that affect the properties and the resulting precision of the machine tools [1–5].

One of the options is virtual modeling of machine tools using the above-mentioned CAD programs. It is virtual machining on a virtual model of a machine tool modeled in a CAD program where its properties are tested on mathematical models. To perform the prototype activity, we decided to use the PTC Creo Parametric CAD system. We have chosen this program because of the knowledge and experience we have acquired during work on other projects, the simplicity of the FEM analysis and its availability in the workplace.

8.2 Definition of the Problem

Mechanical machining on machine tools is based on the principle of cutting off redundant material from the workpiece by relative tool movements relative to it. As a result of this process is the machined part into the desired shape, dimensions, and surface quality. The machined surface of workpiece can be defined from a mathematical point of view as a set of points in the space that represent traces of the tool's functional point (line, face) during his gradual contact with the machining workpiece.

Machine tools with a serial kinematic structure from a kinematic point of view are working on the principle that the resulting relative movement of the tool and the workpiece, required to change the shape and dimensions of the workpiece, results from the superposition of the movements of the individual machine nodes (executive members) which are arranged in succession in the kinematic chain behind from the workpiece to the tool. Instead, each of the executive members in this kinematic chain performs either a single motion (linear or rotational), or does no movement.

The above-mentioned facts can advantageously be used to create a mathematical model of the machined part surface. When creating a mathematical model of a really machined surface on any machine, it is advisable to move from simpler to more complex. For this reason, in this subsection we will not consider the influence of the various inaccuracies of the system machine tool-tool-workpiece-jig on the resultant characteristics (shape, dimensions, surface roughness) of the machined surface, we will talk about the mathematical model of the so-called ideal machined surface, which is created as a trace of the so-called ideal tool trajectory (its functional point, or line or area) on the workpiece.

In the following research, we will consider a production machine having three driven axes, Fig. 8.1.

In the first step, we replace the machine with a mathematical model. Generally, it is best to make the calculation model simple. However, it has to meet the key features influencing its working precision. Subsequently, it is necessary to determine the trajectory equation of the tool in a coordinate system such as the workpiece/component and to determine the influence of inaccuracies bound to the individual nodes of particular machine tools for the overall machining accuracy. Finally, these effects have to be transformed into the workpiece contact area and superposed here.

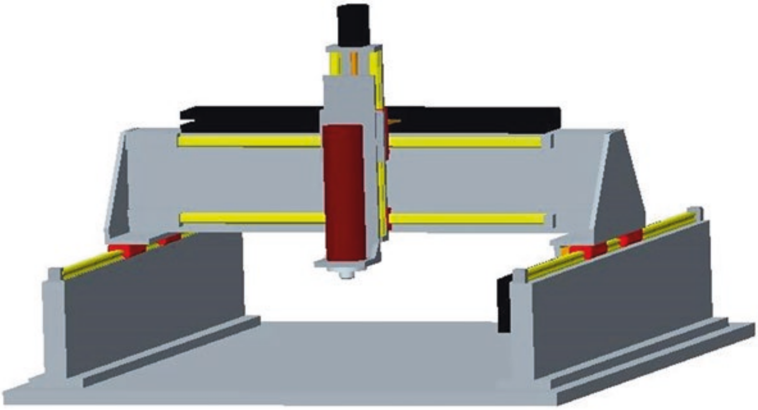

Fig. 8.1 Tri-axis cnc milling machine LMG2A-CB6-CC8 [7]

8.2.1 Making a Mathematical Model of a Machine Tool

At the beginning of the precision analysis of the machine, it is necessary to create a virtual simplified computational model. This computational model must meet all key features that affect its accuracy. All virtual modeling assumes a selected model virtual workpiece, which must be defined at the beginning [1].

When examining work precision analysis of machine tools using their mathematical models, it is necessary to determine the tool trajectory equation in a coordinate system such as the workpiece/component and to determine the effects of inaccuracies bound to individual nodes of particular machine tools for overall machining accuracy. Finally, these effects have to be transformed into the workpiece contact/workpiece and then superposed [1].

Steps of the process of analyzing the mathematical modeling of the accuracy of the production machine:

– Determine the sequence of machine tool nodes—model bodies (movable and stationary) in the direction from the workpiece/component to the tool.
– Determine the coordinate systems of specific model bodies of the calculation model of the machine.
– Mathematically determine the mutual end positions of specific model bodies of the calculation model of the machine tool—column vectors $\{\mathbf{K}_{i+1,i}\}$.
– Mathematically determine the movements of specific model bodies of the calculation model of the machine.
– Mathematically determine the transformation vectors of the direct movements $\{\mathbf{T}_{i+1,i}(t)\}$ and the transformation matrices of the rotational movements $[\mathbf{R}_{i+1,i}(t)]$ of specific model bodies of the machining center model.

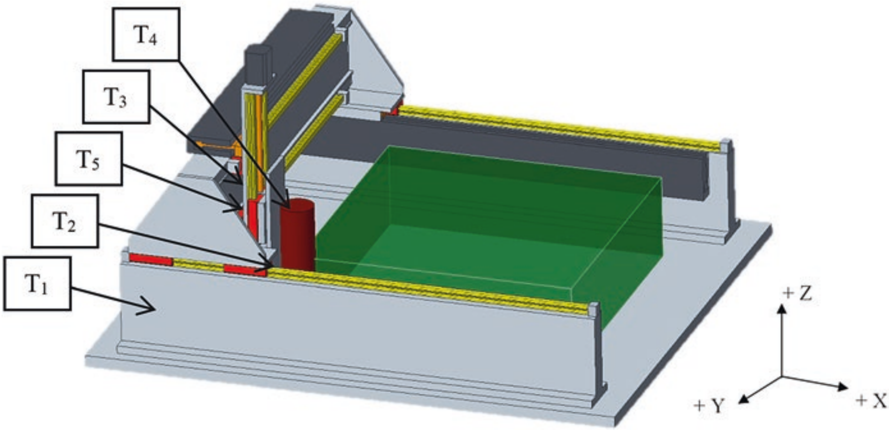

Fig. 8.2 Simplified model of a 3-axis machining center LMG2A-CB6-CC8 [3]

– Mathematically define inaccuracies and deformations of individual model bodies of the machining center model and their time changes during machining [1].

In the mathematical analysis of the machine tool, we need to simplify the machine frame, but only in such a way as to preserve the basic features and charts of the machine frame model. The individual machine nodes can thus be replaced by simplified bodies.

8.2.2 The Concept of the Project

The selected modeling object is a three axis milling machine with a vertical axis of machining with the gantry by arranging the structure [6] (Fig. 8.2). The individual milling bodies are:

T1—bed.
T2—crossbar.
T3—support.
T4—spindle with spindle.
T5—spindle.

8.3 Digital Model of the Machining Center and Ideal Workpiece

The calculation model is available to determine the basic dimensions of the machining center and to display the coordinate systems of each model body. For model bodies T_1 to T_5, transformation matrices of rotational motion, transformation vectors of direct motion, and initial position vectors for the next body were determined. For example, the model body T_1, which is the bed, does not move relative to the stationary workpiece T_0. The workpiece is clamped in the plane X_1Y_1 so that its lower plane and plane of the bed are identified.

For the T_1 to T_5 model bodies, the transformation matrices of the rotational movements, the forward motion transformation vectors, and the starting position vectors for the next body will be determined at the following points. The order in which we perform these tasks has been chosen from the spindle to the machine bed (T_5 to T_1).

8.3.1 Detailed Calculation Model of the Bed

The values of the individual design dimensions are as follows: d_1 = 65 mm, e_1 = 95 mm, g_1 = 40 mm, h = 77 mm, j_1 = 10.7 mm. Dimension v_v represents the height of the line resulting from the construction of the machine (22.7 mm) and the dimension B_{omax} is the maximum workpiece width that can be machined on the machine (Fig. 8.3).

The rotary motion transformation matrix holds true:

$$[R_{10}] = [R_{10}(t)] = [E] \tag{8.1}$$

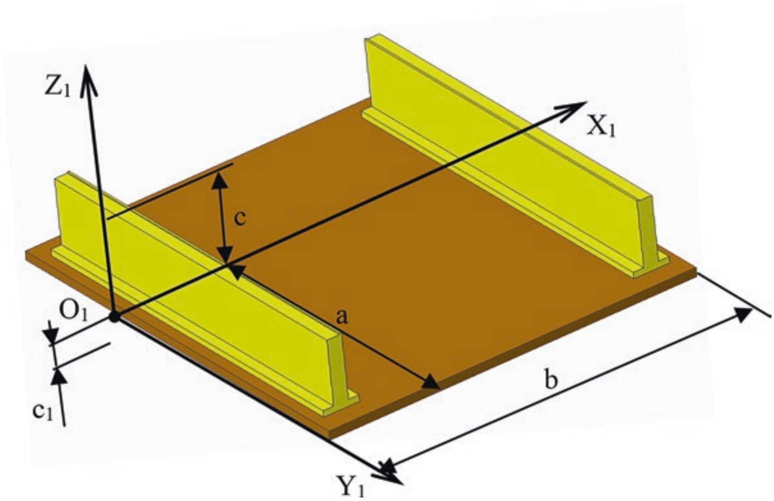

Fig. 8.3 Detailed calculation model of the bed of the milling machine [3]

Transformation vector of direct motion will be:

$$\{T_{10}\} = \{T_{10}(t)\} = \{0\} \tag{8.2}$$

The initial position vector has a shape:

$$\{K_{10}\} = \{-(e_1 + h/2 + B_{omax}/2) - (d_1/2 + v_v + g_1 + j_4 + j_5 + j_1)0\}T \tag{8.3}$$

8.3.2 Detailed Spindle Calculation Model

The values of the individual design dimensions are as follows: d_1 = 65 mm, e_1 = 95 mm, g_1 = 40 mm, h = 77 mm, j_1 = 10.7 mm. The dimension v_v represents the track height resulting from the machine design (22.7 mm) and the B_{omax} dimension is the maximum workpiece width that can be machined on the machine. The rotary motion transformation matrix has a shape at any time:

$$[R_{54}] = [R_{54}(t)] = \begin{bmatrix} \cos\gamma 5(t) & -\sin\gamma 5(t) & 0 \\ \sin\gamma 5(t) & \cos\gamma 5(t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{8.4}$$

Where instantaneous values of angle $\gamma 5$ (t) at any time t can be calculated based on the spindle speed n_v and thus:

$$\gamma 5(t) = \frac{\pi \cdot nv \cdot t}{30}(rad) \tag{8.5}$$

For our machine tool, we think that virtual machining will consider the spindle as immobile (Fig. 8.4). The rotary motion transformation matrix will therefore be unitary:

$$[R_{54}] = [R_{54}(t)] = [E] \tag{8.6}$$

We also do not expect a combination of spindle rotation and rotation, which implies that the transformation vector for:

$$\{T_{54}\} = \{T_{54}(t)\} = \{0\} \tag{8.7}$$

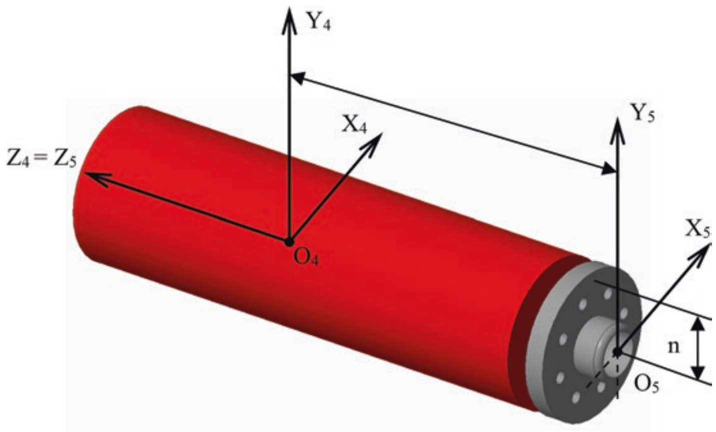

Fig. 8.4 Detailed spindle calculation model of the milling machine [3]

The figure shows that the initial position of the spindle relative to the body T_4 will be:

$$\{K_{54}\} = \{0,0,-o\}T, \tag{8.8}$$

where the value of the constructional dimension o is 0. We also do not expect a combination of spindle rotation and rotation, which implies that the transformation vector for the direct motion will be:

$$\{T_{54}\} = \{T_{54}(t)\} = \{0\} \tag{8.9}$$

8.3.3 Detailed Computational Model of the Support

In the virtual model, the body T_3 is the one that moves directly towards the transverse axis in the direction of the X_2 axis. In the mathematical model, it performs this movement along with the previous T_4 and T_5 bodies. The rotary motion transformation matrix will be:

$$[\mathbf{R}_{32}] = [\mathbf{R}_{32}(t)] = [\mathbf{E}] \tag{8.10}$$

Transformation vector of direct motion will be:

$$\{\mathbf{T}_{32}\} = \{\mathbf{T}_{32}(t)\} = \{\pm u_3(t)\,0\,0\}^T, \tag{8.11}$$

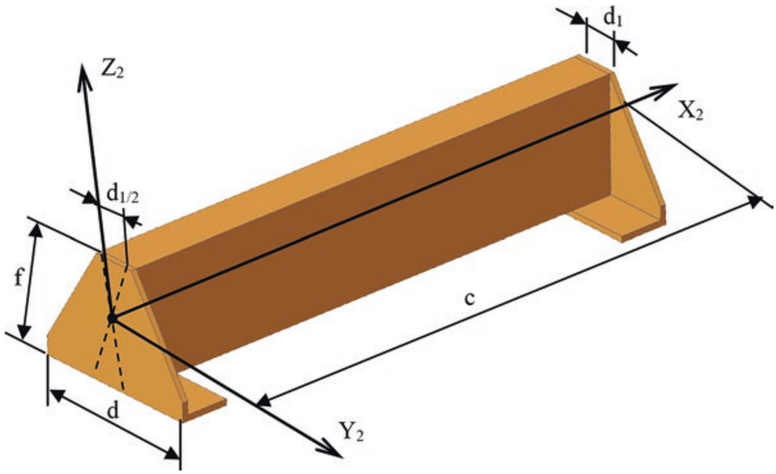

Fig. 8.5 Detailed support calculation model of the milling machine [3]

where u_3 (t) is the value of the instantaneous path that the model body T_3 runs at a given time t, in the direction of the X_2 axis. We determine it by using the direct feed on the milling cutter f_x and thus:

$$u_3(t) = f_x \cdot z_f \cdot n_v \cdot \frac{t[s]}{60} = 0.045 \cdot 4 \cdot 5730 \cdot \frac{t}{60} = 17.19t(mm) \quad (8.12)$$

We assign the mark to the resulting value u_3 (t) according to the direction of movement of the support such that when it moves in the left-hand direction to the right, then the support performs a relative movement in the positive sense of the axis X_2 and the value u_3 (t) > 0 and thus plus (+) (Fig. 8.5). Otherwise, we use the minus sign (−). The co-ordinates of the starting position vector are represented as follows: $x_{03} \in \langle x_{min}; x_{max} \rangle$.

$$y_{03} = d_1/2 + v_v, z_{03} = f/2 - i_1 \quad (8.13)$$

$$x_{min} = e_1 + h/2, x_{max} = x_{min} + B_{omax} \quad (8.14)$$

8.4 Conclusion

The resulting inaccuracy of machining is given by the sum of workpiece deformations caused by technological forces and the inaccuracies of the position of all model bodies (machine tool nodes) from the tool to the workpiece projected into the coordinate system of the workpiece at the appropriate time t.

In virtual machining, it is not possible to numerically simulate the whole model as a numerical simulation, and it is therefore sufficient to perform a numerical simulation analysis at specified points. The track running along the rail with the support, slide, spindle, and tool at time t will be 2000 mm. The entire process of virtual machining will take on the given machining parameters $t \approx 116.346$ s, according to the established relation, it is possible to calculate the machining time of one section $k = 50$ mm and therefore $t_{\Delta} \approx 2909$ s.

From the calculated, measured, and assembled data, it can be stated that our machining center would need some design adjustments to reduce inaccuracies, especially in machining directions Y and Z. The biggest inaccuracies in these directions were for the direction Z = 0.636 mm and for the direction Y = 0.879 mm with parallel milling. For counterbore milling, it was for axis Z = 0.666 mm and for axis Y = 1379 mm. For direction X, the resulting inaccuracies resulted in a fairly good level with parallel milling X = 0.066 mm and counter-milling X = 0.130 mm.

In this way, we get a numerical model of the workpiece inaccuracy that tells us the working accuracy of the machine. The degree of uncertainty of the result depends on the accuracy of the computational methods by which we can determine the appropriate deformations and other inaccuracies of the position of the individual nodes of the examined machine and the workpiece.

Using information technology [8], we analyzed the machine precision and we have saved the cost of experimental testing of the production machine. This is very important in terms of overall reduction in development costs [9].

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Chapter 9
Calculation of Stresses during Shielded Arc Surfacing with Consideration Influence of Temperature and Structure Changes

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9.1 Introduction

In stress calculations during the welding processes of metals and their alloys, the interaction of temperature fields, phase transformations, strains, and stresses is commonly taken into account. The starting point for these calculations is the temperature field, whose changes result in changes in structural component shares (e.g., in steel, cast iron) and changes in the strain fields. Finally, the thermal and structural strains, in conjunction with stress-strain curves, enable the determination of temporary and residual stresses.

9.2 Temperature Field

Two methods are mainly used to calculate the temperature in welding processes: analytical (usually based on integral transformations and Green's functions) [1–7] and numerical: (FEM—Finite Element Method) [8–16], as well as methods of elementary balances and finite differences. In this work, the temperature field is described analytically as the summary temperature increase caused by the action of the electric arc Θ_a and the heat transferred by the molten metal electrode Θ_w [17]:

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$$\Theta(x,y,z,t) - \Theta_0 = \Theta_a(x,y,z,t) + \Theta_w(x,y,z,t) \tag{9.1}$$

where: Θ_0 – initial temperature of material, t - time.

The temperature field caused by the electric arc with Gaussian heat distribution is analytically described in [18], whereas the heat of molten electrode metal as heat source in description of temperature field is considered in [19].

9.3 Analytical Model of Transformation Share Calculation

Kinetics of phase transformations during heating is limited by temperature values at the beginning (A_1) and at the end (A_3) of austenitic transformation. The amount of austenite φ_A created during heating the ferrite-pearlitic steel is defined according to the Johnson-Mehl-Avrami's and Kolmogorov's (JMAK) rule [20]:

$$\phi_A(T) = \sum_j \phi_j^0 \left(1 - \exp\left(-b_j(\Theta) t^{n_j(\Theta)}\right)\right) \tag{9.2}$$

where φ_j^0 constitutes initial share of ferrite ($j \equiv F$), pearlite ($j \equiv P$), and bainite ($j \equiv B$), while constants b_j and n_j are determined using conditions of the beginning and the end of transformation:

$$n_j = \frac{\ln(\ln(0.99))}{\ln(A_1 / A_3)}, b_j = \frac{0.01 n_i}{A_1} \tag{9.3}$$

In welding processes, the volume shares of individual phases during cooling depend on the temperature, cooling rate, and the share of austenite (in the zone of incomplete transformation $0 \le \varphi_A \le 1$). In quantitative perspective, the progress of phase transformation during cooling is obtained using additivity rule by volumetric share φ_j of created phase what can be expressed analogically to Avrami's law by equation [21]:

$$\phi_j = \phi_A \phi_j^{\max} \left(1 - \exp\left(-b_j \Theta^{n_j}\right)\right) + \phi_j^0 \tag{9.4}$$

$$n_j = \frac{\ln\left(\ln\left(1 - \phi_j^s\right) / \ln\left(1 - \phi_j^f\right)\right)}{\ln\left(\Theta_j^s / \Theta_j^f\right)}, b_j = \frac{n_j\left(1 - \phi_j^f\right)}{\Theta_j^s} \tag{9.5}$$

$$\frac{\phi_j^s}{\phi_j^{\max}} = 0.01, \frac{\phi_j^f}{\phi_j^{\max}} = 0.99 \tag{9.6}$$

where: φ_j^0 is volume participation of *j*-th structural component, which has not been transformed during the austenitization, $\Theta_j^s = \Theta_j^s(v_{8/5})$ and $\Theta_j^f = \Theta_j^f(v_{8/5})$ are, respectively, initial and final temperature of *j*-th component phase transformation, φ_j^{max} is the maximum volume share of *j*-th phase for the cooling rate determined on the basis of the continuous cooling diagram, while the sum of volumetric shares φ_j equals:

$$\sum_{j=1}^{k} \phi_j = 1 \tag{9.7}$$

The quantitative description of dependence of material's structure and quality on temperature and transformation time of over-cooled austenite during surfacing is made using the time-temperature-transformation diagram during continuous cooling, which binds the time of cooling $t_{8/5}$ (time when material stays within the range of temperature between 500 °C and 800 °C, or the velocity of cooling ($v_{8/5} = (800–500)/t_{8/5}$) and the temperature with the progress of phase transformation. Those diagrams are called TTT-welding diagrams. The fraction of martensite formed below the temperature M_s is calculated using the Koistinen-Marburger formula [22]:

$$\phi_M(\Theta) = \phi_A \phi_M^{\max} \left\{1 - \exp\left[-\mu\left(\Theta_{Ms} - \Theta\right)\right]\right\} \tag{9.8}$$

$$\mu = \ln\left(\phi_M^{\min}\right) / \left(\Theta_{Ms} - \Theta_{Mf}\right) \tag{9.9}$$

where φ_M denotes volume share of martensite during process, Θ_{Ms} and Θ_{Mf} are temperatures of begin and end of martensitic transformation, $\phi_M^{\min} = 0.1$.

9.4 Strains in Welding Processes

Total strain during single-pass surfacing represents the sum of thermal and structural strains during heating (ε^H) and cooling (ε^C):

$$\varepsilon(x,y,z,t) = \varepsilon^H + \varepsilon^C \tag{9.10}$$

During heating, the strain caused by temperature and phase transformation is determined from the dependence:

$$\begin{aligned} \varepsilon^H = \sum_{i=A,P,F,B,M} &\Big\{\alpha_i \phi_{i0}\left(\Theta - \Theta_0\right) H\left(\Theta_{A_1} - \Theta\right) + \\ &\alpha_i \phi_i \left(\Theta - \Theta_{A_1}\right) H\left(\Theta_{A_3} - \Theta\right) H\left(\Theta - \Theta_{A_1}\right) + \\ &+ \alpha_A \left(\Theta - \Theta_{A_3}\right) H\left(\Theta - \Theta_{A_3}\right) + \phi_i \gamma_{iA}\Big\} \end{aligned} \tag{9.11}$$

where: γ_{iA}—structural strain of i-th structure transformation into austenite, α_i—linear thermal expansion coefficient of i-th structure, and $H(x)$ is the function defined as follows:

$$H(x)=\begin{cases}1 & for\ x>0\\ 0{,}5 & for\ x=0\\ 0 & for\ x<0\end{cases} \tag{9.12}$$

The amount of strain during cooling is determined according to the formula:

$$\begin{aligned}\varepsilon^{C} &= \alpha_A\left(\Theta-\Theta_{SOL}\right)H\left(\Theta-\Theta_s\right)+\alpha_A\left(\Theta_s-\Theta_{SOL}\right)H\left(\Theta_s-\Theta\right)+\\ &+\sum_{i=A,P,F,B,M}\alpha_i\phi_i\left(\Theta-\Theta_{si}\right)H\left(\Theta_{si}-\Theta\right)+\sum_{i=P,F,B,M}\phi_i\gamma_{Ai}\end{aligned} \tag{9.13}$$

where Θ_{SOL}—solidus temperature, Θ_s—initial temperature of phase transformation, Θ_{si}—initial temperature of austenite transformation into i-th structure, γ_{Ai}—structural strain of austenite into i-th structure.

Due to the solid-liquid and liquid state above the solidus temperature:

$$\varepsilon\left(x,y,z,t\right)=0 \quad for \quad \Theta>\Theta_{SOL} \tag{9.14}$$

9.5 Calculation Model of Stresses

The surfaced by welding element is considered, which fulfills the geometric conditions of the rod element, i.e., its length is incomparably greater than the dimensions of its cross-section. To describe stress state has been used prismatic element subjected to mechanical and thermal loads, which for separate cross-sections x are characterized by internal forces $N = N(x)$ and $M_y = M_y(x)$. Remaining forces are assumed to be negligible (transverse forces: $T_y = T_y(x)$, $T_z = T_z(x)$) and absent ($M_x = M_x(x)$). The element is also subjected to symmetric action in relation to z axis in temperature field $\Theta = \Theta(x,y,z) = \Theta(x,\text{-}y,z)$. The stress state of the element is characterized by single dimensional stress state $\sigma_x = \sigma_x(x,z,t) = \sigma_x(x,\text{-}y,z,t)$ (Fig. 9.1).

In order to derive formulas on strain and displacement of flat, Cauchy's relation has been used and planar section hypothesis has been assumed. Instead, integral conditions of equilibrium using simple Hooke's law $\sigma_x = E\varepsilon_x$ are applied [23]. For modulus of longitudinal elasticity changeable towards coordinates (heterogeneous material of flat) or Young's modulus dependent on temperature, stress can be described by:

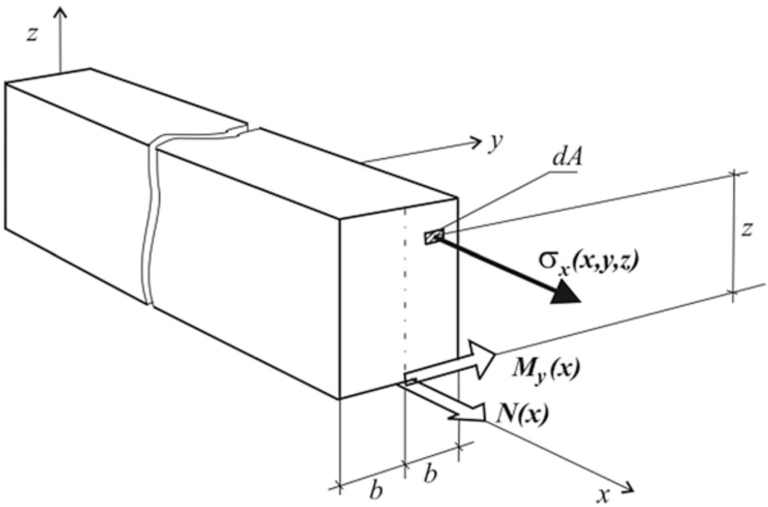

Fig. 9.1 Scheme of a thermally and mechanically loaded element

$$\sigma = \frac{E}{A^E J_y^E - \left(S_y^E\right)^2} \left\{ J_y^E \left(N(x) + N^\Theta \right) + S_y^E \left(M(x) - M_y^\Theta \right) + - A^E \left(M(x) - M_y^\Theta \right) + S_y^E \left(N(x) + N^\Theta \right) z \right\} - E\varepsilon_0 - \alpha E \Theta \tag{9.15}$$

$$A^E = \int_{(A)} E dA \quad S_y^E = \int_{(A)} Ez dA \quad J_y^E = \int_{(A)} Ez^2 dA$$
$$N^T = \int_{(A)} \alpha E \Theta dA \quad M_y^T = \int_{(A)} \alpha E \Theta z dA \tag{9.16}$$

The stresses in elasto-plastic state are determined by iteration using method of elastic solutions at the variable modulus of longitudinal elasticity conditioned by the stress-strain curve [24]. Dependence of stresses on strains is assumed on the basis of tensile curves of particular structures, taking into account the influence of temperature.

9.6 Example of Calculation

Calculations of temperatures, structural component shares, strains and stresses, for a square steel element with the side length 0.2 m and thickness of the plate 0.03 m made from steels S355J2G3 have been conducted. Thermal properties of surfaced element and electrode materials have been determined by $a = 8 \times 10^{-6}$ m²/s, $C_p = 670$ J/kg K, $\rho = 7800$ kg/m³, and $L = 268$ kJ/kg.

Numerical simulations have been conducted for the welding heat source of power 12,121 W, which corresponds to welding parameters (U = 30 V, I = 400 A, η = 0.99). In calculations, there were assumed welding velocity v = 0.007 m/s, electrode wire diameter d = 3.5 mm, wire feed speed v_e = 0.031 m/s, and bead dimensions h_w = 2.5 mm and w_w = 22 mm (d_p = 0). The initial value of temperature of electrode T_e = 100 °C (a temperature of contact tip with the welding head). Computations have been made for middle cross-section of the surfaced element.

Isolines of the maximum temperature in the cross-section of the welded joint make it possible to determine the boundaries of characteristic heat affected zones.. The calculated isotherm 1493 °C determines the fusion line and isotherms A_3 and A_1 determine the partial and full austenitization zones (Fig. 9.2a). In this figure, the selected cross-section points were marked, for which a stress analysis was performed. The temperatures A_3 = 920 °C and A_1 = 748 °C have been calculated taking into account the effect of heating rate on these temperatures [25]. The photograph of a metallographic macrosection in the middle cross-section is shown in Fig. 9.2b. Calculated solidus isotherm 1493 °C (solidification temperature of steel)—black line—corresponds to the fusion line obtained in the experiment. Bright line corresponds to the calculated temperature A_3—of the full austenite transformation.

During heating, when the temperature exceeds *A*, the austenitic transformation occurs, which ends at A_3 temperature. During cooling, the temperature of the start and end of phase transformations was determined on the basis of TTT-welding diagram for S355 steel shown in Fig. 9.3 [26].

Expansion coefficients of individual structural elements and structural strains determined on the basis of the author's own dilatometric research (Table 9.1) [27] were used in strain calculations.

Stress-strain curves for ferrite and pearlite are determined using the results of experimental studies contained in [28, 29]. In the case of bainite and martensite structures, stress-strain functions were estimated based on the results of the works [30, 31] and according to Swift law [32].

Figure 9.4 presents the distribution of residual normal stresses in the cross-section of the whole element, while for the middle part of cross-section—has been presented in Fig. 9.5. In Figs. 9.6 and 9.7, the history of stress state changes at selected points of cross-section has been presented (please compare Fig. 9.2a).

At point *1* from the weld zone, the stress plot (Fig. 9.6a) begins with solidification of the deposited metal. During cooling after solidification, tensile stresses

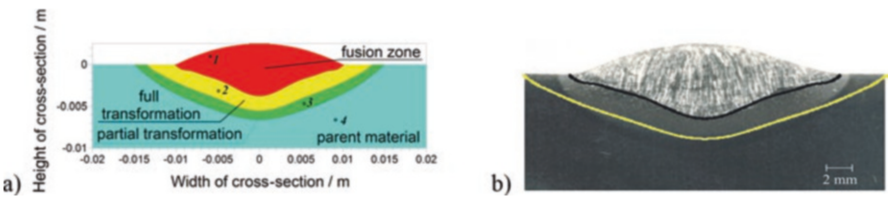

Fig. 9.2 Estimated heat affected zones (**a**) and comparison of experimental zone limits with theoretical results (**b**)

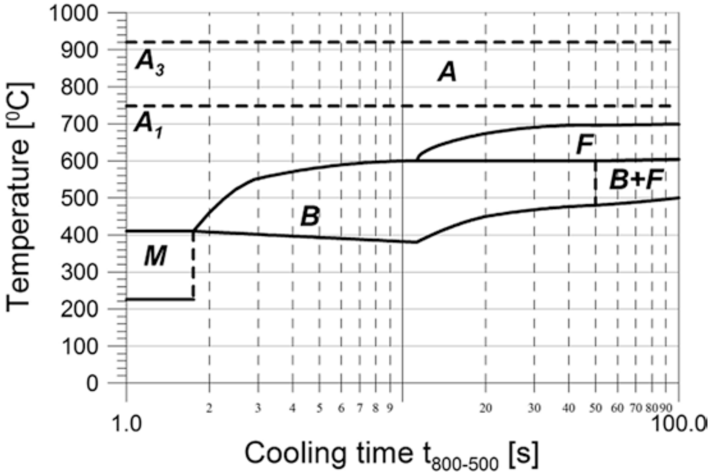

Fig. 9.3 Time-Temperature-Transformation-welding diagram of S355 steel

Table 9.1 Structural (γ) and thermal (α) expansion coefficients of phases [27]

Structure	α [1/°C]		γ
Austenite	2.178×10^{-5}	$\gamma_{F,P,S \rightarrow A}$	1.986×10^{-3}
Ferrite	1.534×10^{-5}	$\gamma_{B \rightarrow A}$	1.440×10^{-3}
Pearlite	1.534×10^{-5}	$\gamma_{A \rightarrow F,P}$	3.055×10^{-3}
Bainite	1.171×10^{-5}	$\gamma_{A \rightarrow B}$	4.0×10^{-3}
Martensite	1.36×10^{-5}		

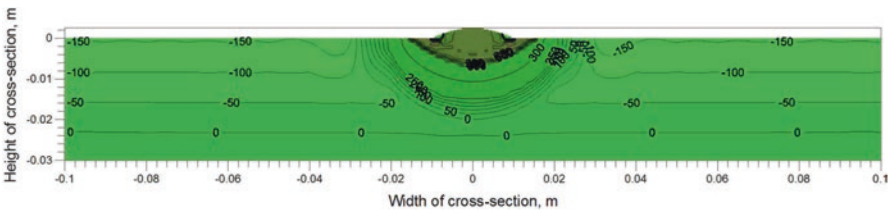

Fig. 9.4 Distribution of residual normal stresses in the cross-section

increase. A sudden change of the line graph and the formation of compressive stress is caused by the phase transformation. At point *2* (Fig. 9.6b) from the area of full transformation due to the heating, the compressive stresses occur. Then, due to transformation of initial structure into austenite, the compressive stresses diminish and go into tensile stresses. Further cooling results in a linear increase in tensile stress up to the conversion of austenite into the cooling structure. Then structural deformations connected with phase transformations (austenite has a lower density than other structures—volume reduction) result in temporary decreases in the stress value, which is visible in the graph in the form of characteristic faults. At point *3*

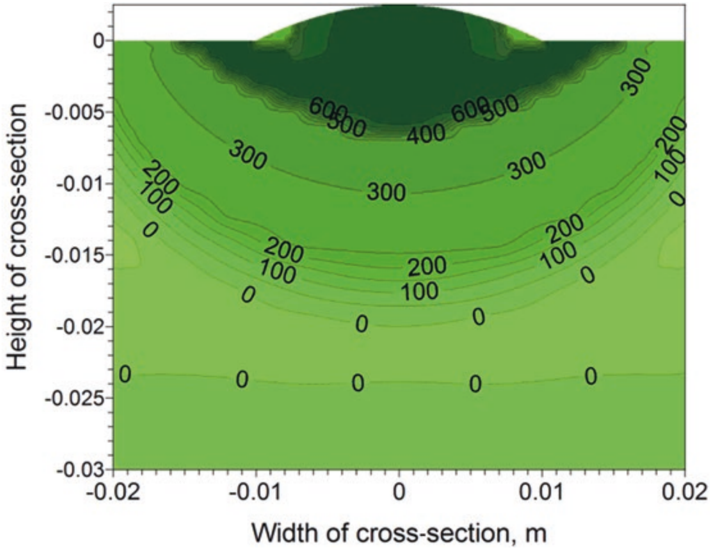

Fig. 9.5 Distribution of residual normal stresses in the middle part-area of cross-section

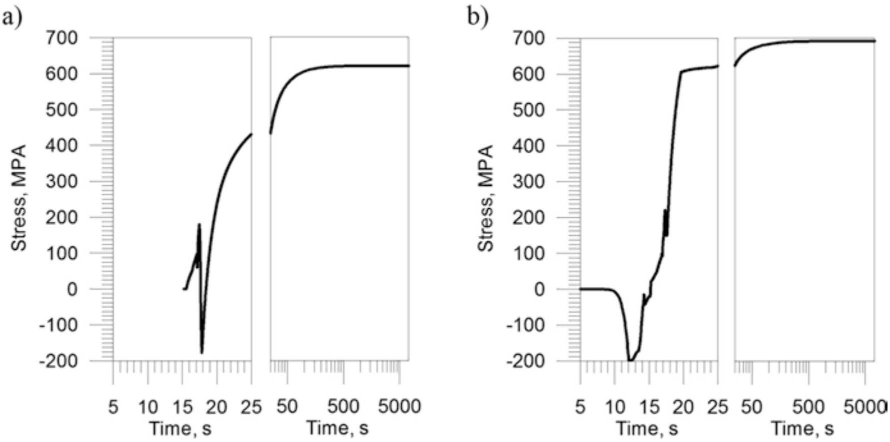

Fig. 9.6 Stresses during surfacing at points: *1* (**a**) and 2 (**b**)

from the area of incomplete transformation (Fig. 9.7a), compressive stresses increase during heating, but then due to austenitization stresses change sign and overpass into tensile. During further cooling, austenite transformation into ferrite and pearlite takes place, and structural deformations disturb the state of stress, which is visible in the form of bends on the line of increasing tensile stresses. Point 4 is outside the heat affected zone and the material has not experienced any structural changes at this point. Stress at this point (Fig. 9.7b) is the result of thermal

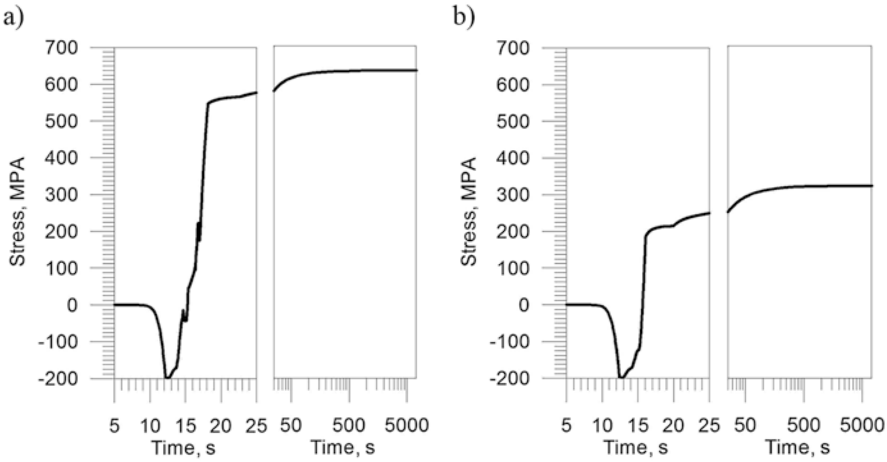

Fig. 9.7 Stresses during surfacing at points: *3* (**a**) and 4 (**b**)

strains (compressive stresses during heating and tensile stresses during cooling) and of the stress equilibrium of the entire cross-section.

9.7 Conclusion

The presented analytical descriptions and developed calculation models allow one to estimate the influence of temperature and structure changes on the strain and stress fields of arising during shielded arc surfacing. Calculated temperatures, volumetric shares of structural components and stresses in surfaced elements enable:

– determine the actual shapes and dimensions of the heat affected zone, particularly the melting zone (fusion line),
– follow the changes in temperature, shares of structural components, strains and stresses in any point of surfaced element,
– study the development of the stress field, strain plastic zone during process and residual stress distribution after shielded arc surfacing.

The calculated stresses, whose distribution is characterized by tensile stresses in the weld and full transformation zone by compressive stresses outside the heat affected zone, are confirmed in the literature, e.g., in experimental studies of Paradowska et al. [33] and Chang et al. [34]. Similar distributions were obtained in numerical simulations conducted using Finite Element Method by Jiang et al. [35].

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Chapter 10
Emulation of Wheel Speed Sensors for Automotive Electronic Control Unit

Juraj Pančík and Vladimír Beneš

10.1 Introduction

This work presents educational tool for the teaching of modern trends in automotive electronics. The aim was to develop an embedded system with functions of emulation of some peripherals which are intended for automotive electronic control units (ECU, Electronic Control Unit). The ECU is surrounded with peripherals (e.g., by sensor and another hardware parts) and it interacts with their surroundings via car's buses (e.g., CAN, LIN, FlexRAY) or via cable harness and electromechanical systems (e.g., ignition switch or EPB switch). ECU system tests serve to test all required functions ECU. For operations of ECU during system tests is typical that these activities are consistent with the ECU in the car. It is necessary to emulate ECU's peripherals during system tests. Therefore, emulation of the ECU's peripherals is not only suitable for educational use of the future technicians and engineers but it may also be useful for preparing ECU system test. In the next text, it is necessary to understand the differences between simulation and emulation. A simulator is an environment which models but an emulator is one that replicates the usage as on the original device or system. Simulation is when you are replicating, by the means of software, the general behavior of a system starting from a conceptual model. Emulation is when you are replicating, in a different system, how the original system actually internally works considering each function and their relations. In other

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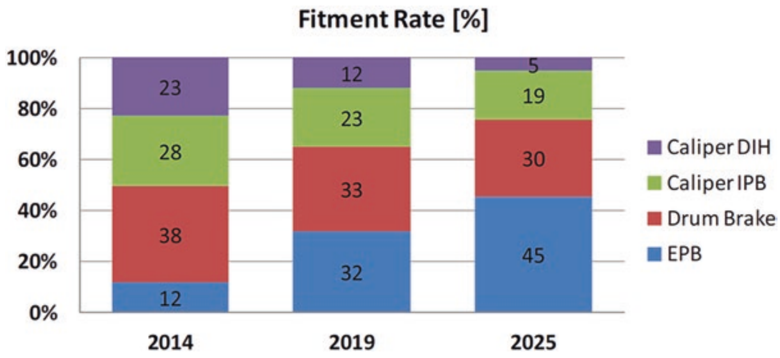

Fig. 10.1 EPB forecasted fitment EPB fitment rate [%] [1]

words, simulation is based on a software implementation of a model where the internal functions of the original systems are not taken into consideration (e.g., a “flight simulator” does not have any “component” of an actual aircraft). Emulation is a replica of the internal system functions on a different host (e.g., on a microcontroller platform). Emulators can also be strictly hardware based and is normally based on a partial or complete “reverse engineering” phase (Fig. 10.1).

10.2 Analysis

10.2.1 Description of EPB System

Since the EPB was first launched in 2001, the number of its functions continues to rise significantly. The EPB offers by far more than the basic application and release of a conventional parking brake. It interacts with several other driver assistance systems. The driver experiences the EPB system by its functions. He expects safety and reliability at low “costs of ownership” with a highly comfortable “look and feel.” The system supplier needs to translate these mainly subjective expectations into physical characteristics of the system and design its components against measurable targets. Figure 10.2 gives an overview of the EPB system with the functionality perceived by the driver on the one hand and the components with their technical characteristics on the other hand. The EPB system consists of the mechatronic actuators that generate the clamp force necessary to safely hold the vehicle, the conventional calipers that convert clamp force into brake torque, electronic hardware with the Electronic Control Unit (ECU), cable harness and switches and especially the control software providing the functions that the driver will experience. A modern approach is to integrate the EPB control unit into one ECU in the car with name electronic stability control system (ESC ECU) [1]. In the market, there are Original Equipment Suppliers (OES)-specific solutions as well as OES-independent combinations from different ECU ESC and EPB suppliers. The latter case is commonly

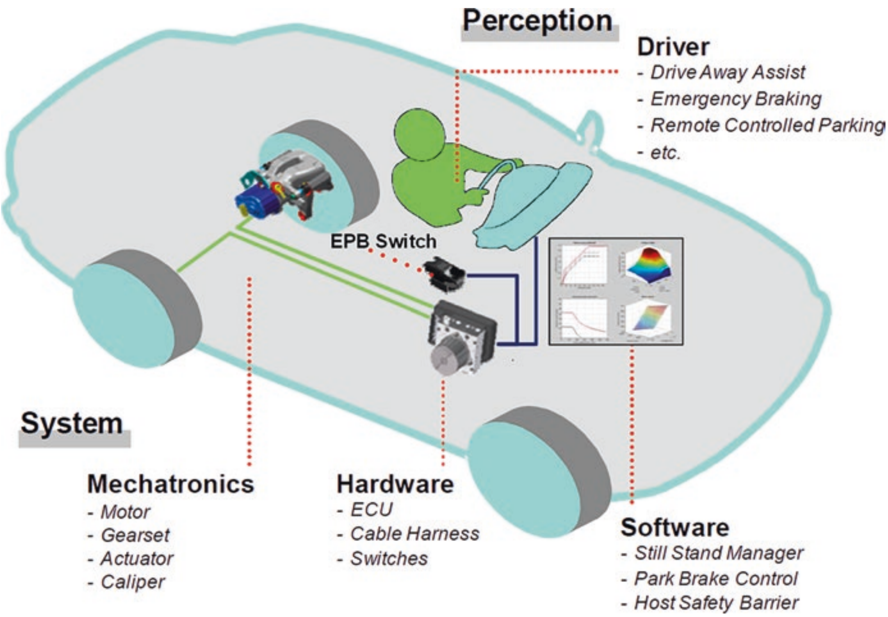

Fig. 10.2 Electric Parking Brake System [1]

called crosswise integration of products from different suppliers, and it is dictated and originated in modern global market with automotive components. The integrated EPB system can be divided into two parts: (1) One part of the EPB system contains the parking brake actuator, the parking brake caliper and the actuation logic (Park Brake Control, PBC), (2) The second part of the EPB system, also called the host, contains the EPB power electronics and necessary peripherals and EPB controls the functions as a part of the ESC ECU's embedded software. In crosswise integration projects, the OES-EPB is responsible for the first part and the OES-ESC for the second part. The aims of this division are: (a) encapsulation of knowledge about particular components, (b) clearly defined areas of responsibility, (c) independent testing and approval of components from the different suppliers, (d) enabling manufacturer-specific levels of functionality of the individual components. The development and release of such integrated systems needs clear requirements for the interfaces and rules for collaboration between the development partners.

10.2.2 Peripherals of Electronic Stability Control (ESC ECU) with EPB Functionality

The block diagram of the ECU with ESC EPB functionality is showed in Fig. 10.3 [2]. According to it, there are two types of peripherals for ESC ECU—peripherals connected to the car's buses (CAN or FlexRAY) and peripherals directly connected to the

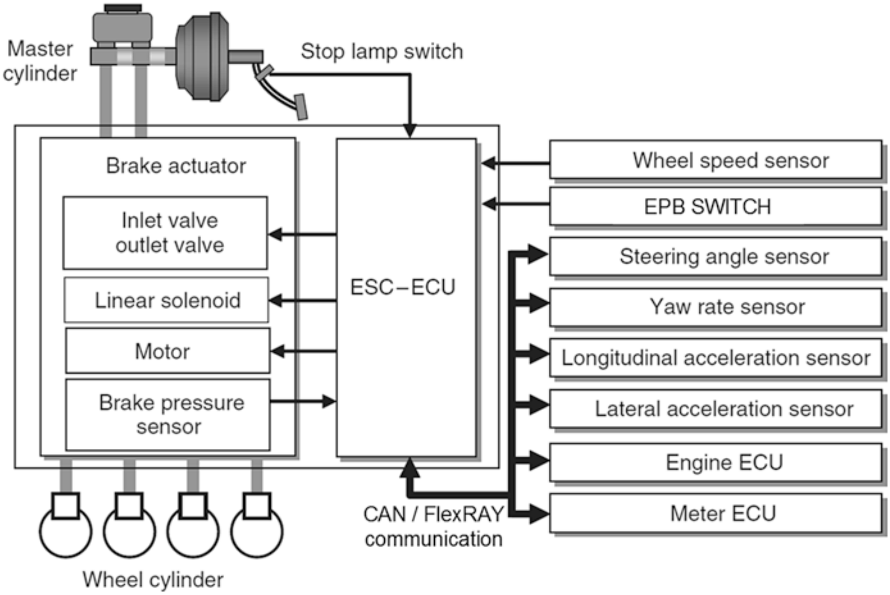

Fig. 10.3 ECU type ESC with EPB functions configuration, adopted from [2]

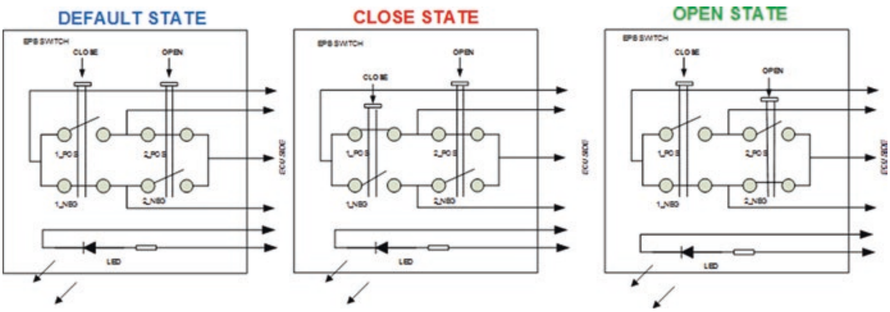

Fig. 10.4 Three basic states of EPB electromechanical switch, adopted from [2]

ECU (wheel speed sensors and the EPB switch). The EPB classical electromechanical switch is connected to the ESC ECU with 6 wires (with states: default open, close, Fig. 10.4) or with 8 wires (with AutoHold function). Four pieces of wheel speed sensors (WSS) are connected to the ESC ECU each with two wires and they communicate with ECU by using current signals (the principle of current loop).

10.3 Design

Wheel speed sensors (WSS) are components with analog current output. WSS are produced as devices with 2 levels (2 L) of current outputs [3] and with 3 levels (3 L) of current outputs [4]. Therefore, information about wheel position is encoded by two or three levels of current (7 mA, 14 mA, and 28 mA current levels). For determine of exact position of the wheel, we need to know the wheel circumference and the number of magnets placed around the perimeter of the wheel. LIN (Local Interconnect Network) is a cost-effective and deterministic communication system for connecting ECUs with smart sensors and actuators. The EPB electromechanical switch is in our contribution modified by utilization of the LIN bus, see more in the US patent [5]. Instead normally 6 or 8 wires we use only 3 wires. The trends reducing of number of peripherals wires by utilization of LIN bus can be seen in all modern cars [6]. In our solution of peripherals emulator we tried to use a maximum amount of modern technology well known in the community of developers. We use hardware platforms as Linux-based minicomputer—Raspberry Pi and as 8 bit AVR microcontroller for real-time signal processing—Arduino Micro. The information system architecture is based on the web server and web browser client and programming was done in JavaScript language for the client (AngularJS framework [7]) and also for server (Node.js [8]).

Figure 10.5 shows the architecture of the embedded system—right side represents the ECU (“Phantom” ECU side) and it consumes voltage and current signals from emulators at left side. The heart of each emulator’s part is Arduino Micro. The programs for all four Arduinos we developed in Arduino IDE environment which is enriched with many libraries and with like C programming language [9]. On the both sides, the Arduinos work besides programs in main loop also with programs which were written in interrupt routines. Main loop ensures state machine control and I2C bus communication. Interrupts are derived from serial port (RX or TX) or from internal timers and digital inputs. All distributed Arduinos are controlled via I2C bus from Raspberry Pi [10]. Both Raspberry Pi units have server’s role and they have installed Node.js [8]. This server’s solution can be programmed with JavaScript language. It means that both sides, clients and servers, can be programmed with common JavaScript language. It includes not only programming of the web server but also the control of I2C hardware pins for Raspberry Pi at the I2C master side [11]. There are two client’s websites in this embedded solution. One website serves for setting of parameters for peripheral emulation and another website serves for reading data captured at the ECU side. The developing of both client’s websites we done with utilization of JavaScript-based open-source front-end web application framework AngularJS [7] and dynamic JSON data resources which represent inputs/outputs data ARDUINO’s.

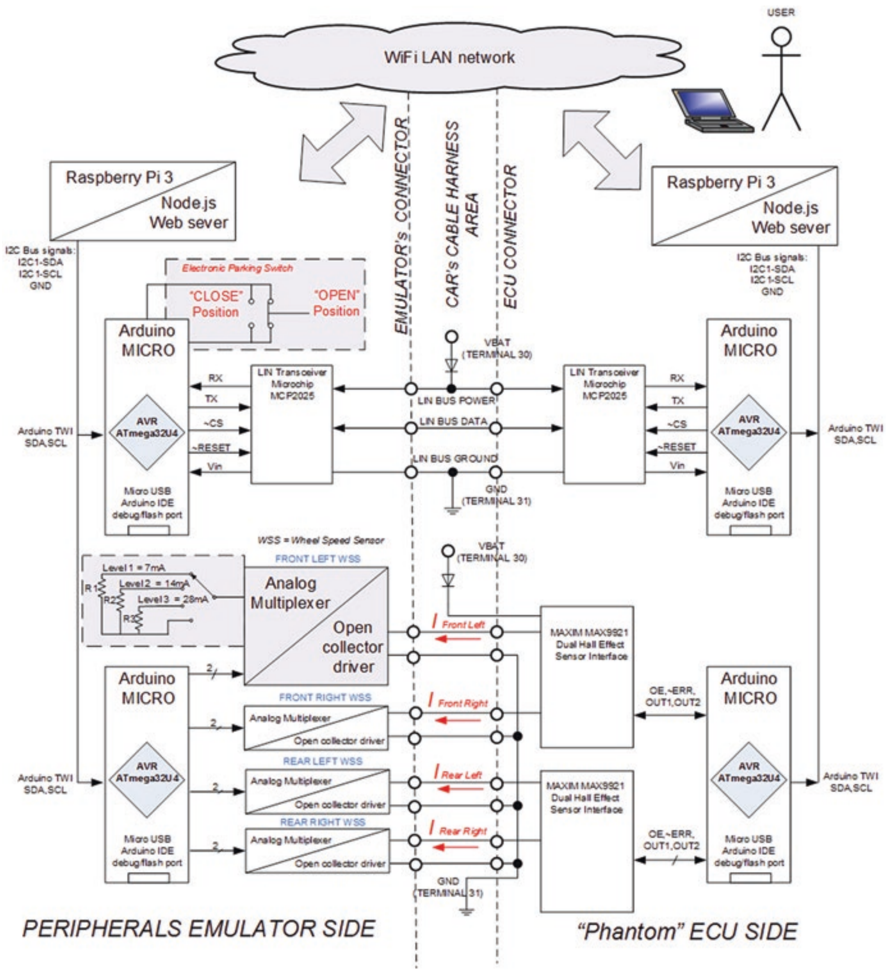

Fig. 10.5 Block diagram of the developed educational system for ECU peripheral's emulation

10.4 Implementation

10.4.1 WSS Emulator

We emulate all four car's WSS with 2 or 3 levels current output signal. Computing power of Arduino Micro can serve only for two wheel's pair emulating and it can't independent emulate of each WSS individually. We can emulate independent front wheels pair as two levels WSS and rear wheels pairs as three levels WSS (or vice versa). Current level pulses were generated via combination of digital controlled analog multiplexer as voltage level selector and open collector driver as voltage–current transformer. Two levels WSS (BOSCH DF11 and DF30, (see Fig. 10.6)) can

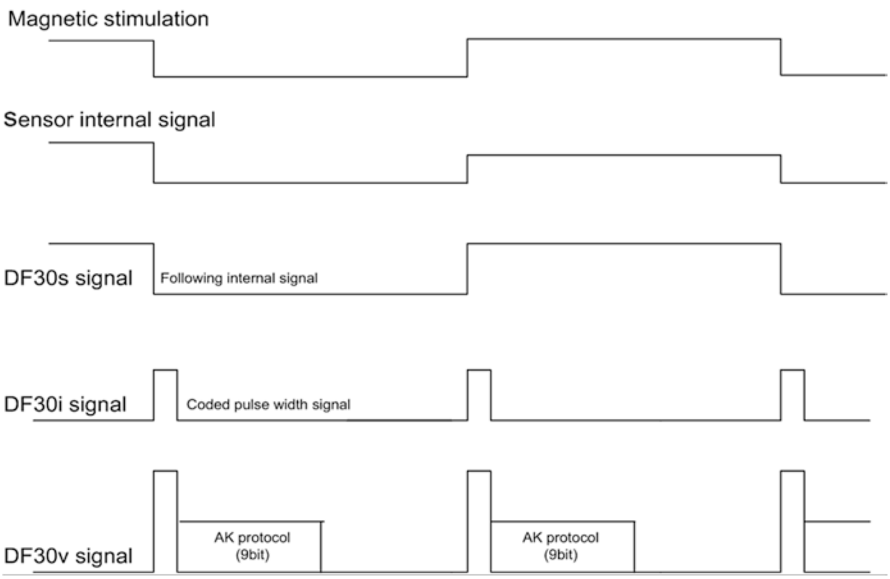

Fig. 10.6 Wheel speed sensors signal protocol type s, i, v [3]

be offered with different signal protocols [3]. The "s" protocol is a square wave signal as rotary speed signal. The "i" protocol is a square wave signal with additional information which is transmitted in the pulse width modulation (PWM) protocol. The width of the square wave impulse includes additional information, while the time between one pulse and the next determines rotary speed information. The "v" protocol is a three level current signal that provides wheel speed information and additional information in a serial data protocol in accordance to the "AK-Protocol" [12]. The magnetic sensor on the wheels perimeter generates an output protocol after every detected magnetic signal flank; therefore, its output signal frequency is twice as high as the standard "s" protocol variant. At emulator's ECU side, we use detection current level pulses from each pair of WSS for ECU dedicated front-end device MAX9921 [13] and ARDUINO Micro (Fig. 10.5) as device for real-time capturing logic level signals from front-end MAX9921. Arduino Micro also ensures I2C communication with up level Raspberry Pi 3 minicomputer. Figure 10.7 shows our real measurements of output current for emulation of DF11i in stop vehicle state ("standstill mode").

10.4.2 *EPB Switch Emulator*

Implementation of the EPB switch is based on the implementation of one pair of LIN bus nodes. One node is the master (ESC ECU side) and second one is the slave (EPB switch emulator side). The implementation of such pair is a non trivial task

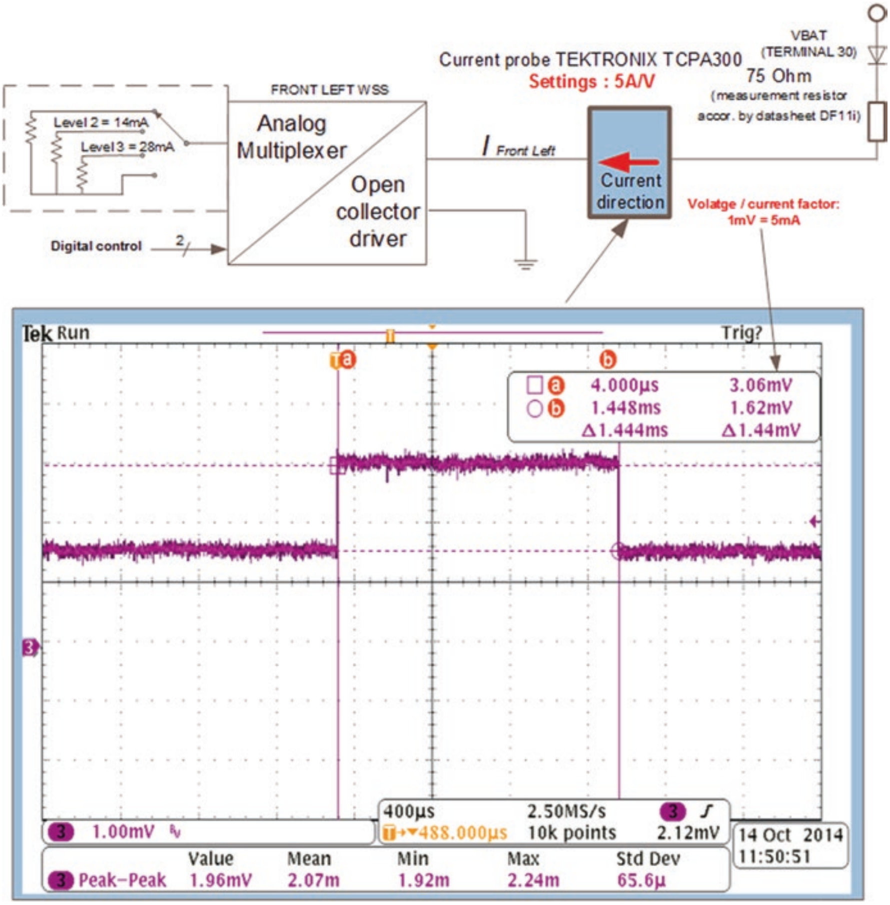

Fig. 10.7 Emulation of the WSS DF11i–standstill idle current pulse (zero velocity)

from technical point of view but it represents challenge also from functional safety reasons. EPB switch can play crucial role in car's safety. In order to demonstrate these approaches, we added to the standard LIN bus protocol additional safety options. Figure 10.8 shows the screenshot from LIN bus communication monitor used by us. This shows LIN bus communication frames recorded between ESC ECU node and EPB switch emulator node. Each row (record) represents one frame of LIN bus communication. First byte represents the command from MASTER and the remaining bytes represent a SLAVE answer from emulator's side. The enhanced checksum is defined by LIN bus standard as checksum including the data bytes and the identifier in addition and it is carried in the last (5th) byte of the frame. The EPB switch states are coded in the third byte (Open, Close, and Default). The checksum is calculated by slave node (EPB switch), e.g., by Arduino Micro's 8-bit AVR processor. We developed additionally two security options. First is the implementation

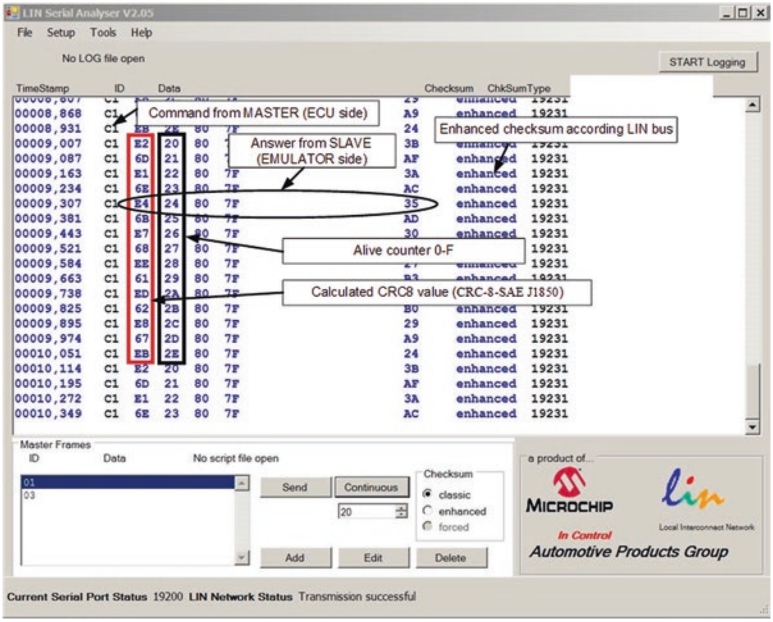

Fig. 10.8 LIN bus communication frames between ECU side (MASTER) and LIN EPB switch emulator (SLAVE)

of the so-called alive frame counter (high nibble of second byte in the frame), second option is calculation of additional checksum known as cyclic redundancy check byte (first byte in the frame). Both security options are defined in AUTOSAR standard. For calculation of CRC sum used the algorithm according AUTOSAR E2E Profile 1 [14] and it is known as CRC-8-SAE J1850. Calculation of this checksum is also provided by AUTOSAR CRC library, which typically is quite efficient and may use hardware support. We found useful educational information about CRC-8-SAE J1850 calculation and implementation details in [16]. The issue of functional safety for LIN bus-based ECU peripherals according to automotive function safety standard ISO 26262 is beyond scope of this chapter [15].

10.5 Conclusion

This chapter deals with analysis, design, and implementation of the equipment that is designed for emulation of signals dedicated as inputs for electronic stability control ECU. We developed emulators of two key peripherals: one for wheel speed sensors (both two and three current levels types) and second for EPB switch. The main goal of our work was developing an educational system which is based on modern open-source technologies. This embedded system is based on the state-of-the-art embedded server-client software solutions with JavaScript. Besides these educational aims, we try to coexist with modern automotive trends—alignment of high level functional safety requirements together by using peripherals which are equipped with car's buses. As illustration of these principles, we proposed the EPB switch based on the LIN bus. Our possible contribution may be in the implementation of modern AUTOSAR network safety mechanism and parts of master/slave LIN bus state machines at open Arduino platform.

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Chapter 11
Information System for Computer-Aided Fixture Design

Vitalii Ivanov, Ivan Pavlenko, Svitlana Vashchenko, and Jozef Zajac

11.1 Introduction

Manufacturing has transformed from local-based to communication-based automation technology. Computer integrated manufacturing systems include an integration of CAD, CAM, CAE, CAPP, CAQ, and CAT systems. The areas of CAD, CAM, CAE, CAPP, and CAQ have been studied for many years and much progress has been made. CAT includes two aspects: (1) cutting tool design and selection; (2) fixture design and fabrication. Fixture design is always a hotspot of computer integrated manufacturing.

Computer-aided fixture design (CAFD) systems are traditionally classified by the level of automation and by the functionality. CAFD as one of the elements of computer integrated manufacturing allows to implement the fixture life cycle from design to its manufacturing, actualizing the geometric modeling and engineering analysis, process planning and automation of the manufacturing. The analysis of the data flows confirms that the CAFD structure must be built considering the integration of these systems.

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11.2 Literature Review

In the past 30 years, CAFD has been recognized as an important area. For many years CAFD has been the focus of academic research with significant progress in both theoretical and practical studies. The most significant contribution to CAFD research was achieved by both individual researchers and specialized research laboratories.

For designing the fixture configurations, as well as to solve local tasks in the fixture design, different methodologies are used: case-based reasoning (CBR) [1, 2], rule-based reasoning (RBR) [3], genetic algorithm (GA) [4, 5], neural network (NN) [6, 7], feature-based fixture design methodology [8], blackboard-based design [9, 10], instructional technology (IT) [11], machine learning [12], graph theory [13], ant colony algorithm (ACA) [14], finite element method (FEM) [15], geometric approaches [16], fuzzy logic [17], multi-agent approach [18], and others [19]. To improve design procedures, methodologies have emerged that are a combination of existing ones. For example, a combination of CBR with other methodologies such as RBR, fuzzy logic, model-based design, GA, NN [20], or ANN and design of experiments (DOE), GA and FEM [21], GA and NN [22], as well as more comprehensive: RBR-fuzzy logic and Chebyshev distance metric [17], GA/NN and machine learning [23].

11.3 Research Methodology

11.3.1 CAFD System

CAD systems are complex systems, which integrate their individual modules—subsystems. Consequently, the design of such systems should be realized using the systematic and comprehensive approach [24]. This approach allows designing a system model considering both the properties of subsystems and the connections between them. Decomposition of such systems with the purpose of allocating separate subsystems allows designing an efficient model, which considers all aspects of the further system. According to the proposed approach, the CAD system can be generally presented by the following dependence:

$$S = \{Ind, Prp, Atr, Inp, Out, Str\}, \tag{11.1}$$

where *Ind* is designation of the system, *Prp* is purposes of the system, *Atr* is general attributes and characteristics, *Inp* is system input, *Out* is system output, $Str = \{E, R\}$ is structure of the system, *E* is system components with the relationships *R* between them.

Considering the subject area for operating the designed system, the identifier *Ind* is determined as “Computer-Aided Fixture Design (CAFD).” The main purpose *Prp* of designing the system for the computerization of engineering activities, including the CAFD system, is to intensify and increase an efficiency of the fixture design process. Input and output system information is determined by the analysis of technical design process. Since the CAFD system ensures execution of settlement operations for the specified stage, the system input *Inp* is information contained in the technical task and obtained at the previous stages of designing.

In general, the system output *Out* is an optimal layout model with its design and technological parameters. There are system-specific characteristics *Atr* as attributes of the designed system: for engineering purposes, specialized or individual. The structure *Str* of the CAFD system is presented and described in detail in the research paper [25].

The object of CAFD automation as the process of fixture design consists of separate stages. As a result of a detailed analysis of the design process, the process-oriented model is compiled [26]. This model determines the list of the stages and their order, establishes the informational and other relationships between them. The first level decomposition diagram is presented in Fig. 11.1. It presents a summary description of the procedure for fixture design.

It should be noted that design process is accompanied by a large number of processing and transferring information between the executed stages. Particularly, it is needed to join a significant amount of background information for obtaining the final result. After the general systematization, it is necessary to organize the data processing within 15 categories, which includes information about the parts of fixtures and other auxiliary information.

11.3.2 Information Support Structure

The CAFD system operates not with the objects of designing (i.e., fixtures), but with information about them. Analysis of all the information categories allows classifying them into two subgroups (Fig. 11.1):

- normative reference information contained in regulatory documents or reference books; its contents can be considered as permanent or nominally constant for a significant number of operating steps.
- information about the material and technical resources is ordered and systematized databases, which ensure an execution of settlement procedures.

The first subgroup data determines methodical information about technological processes or methods for workpieces machining. As a permanent regulatory information, it is sufficient to create the appropriate sections of the information referral system for its storing in the CAFD system. All the technological information data, operating and machining parameters, as well as locating and clamping charts are presented within this approach.

Conversely, information about the material and technical resources for ensuring assembling the fixture describes an array of options for the implementation of its functional elements. Thus, using databases is expedient to save information about the locating and clamping elements of fixtures, cutting tools, materials, and assembly sets of fixtures. The information scheme of the database is fragmentally presented in Fig. 11.2.

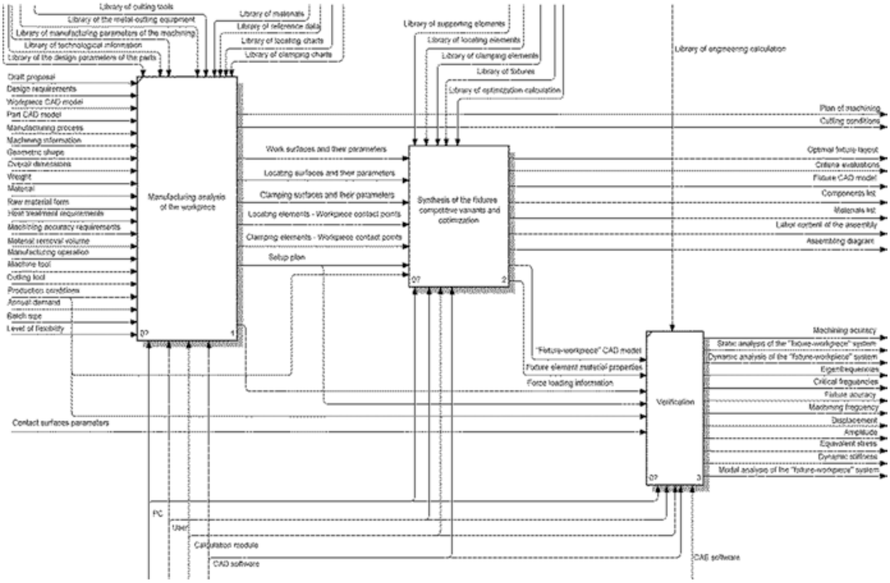

Fig. 11.1 The decomposition diagram for fixture design

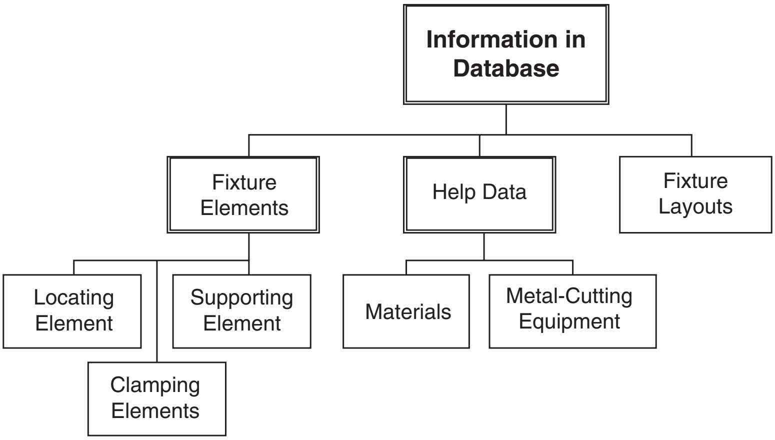

Fig. 11.2 Scheme of the data presentation (fragment)

11.3.3 Database Structure

According to the developed scheme (Fig. 11.2), designing the database is realized for storing all the necessary information. There are five tables created within this database (Fig. 11.3).

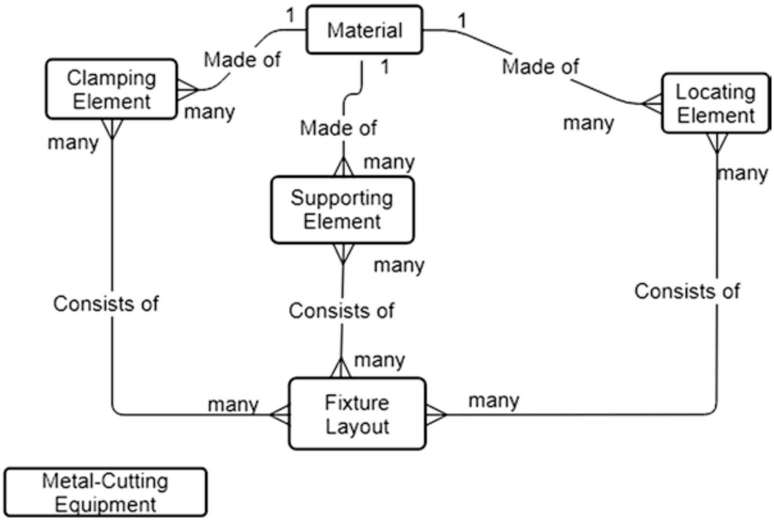

Fig. 11.3 Conceptual model of the subject area

The tables "elementS", "elementC", and "elementL" contain information about supporting, clamping, and locating elements, correspondently. The tables "material", "cuttingEquipment", and "fixtures" contain information about material properties, cutting equipment, and sets of fixtures.

The list of attributes is stated for each database model, which characterize the operating procedures needed to be executed. Additionally, the relationships between the abovementioned tables are established. The relation model is presented in Fig. 11.4.

The table "elementS" contains the nomenclature of 26 supporting elements (i.e., supporting plates, cubes, columns, corners), which are the basis for creating fixture sets. The table "elementL" contains 35 different locating elements (i.e., locating plates, supports, V-blocks, pins) for implementation of a theoretical locating chart. The table "elementC" contains the list of nine clamping elements (i.e., straps, clamps, levers, trims) for ensuring reliable clamping of the workpiece in a fixture during the machining process.

The abovementioned tables contain the general technical characteristics of each functional element including the code, overall and attachment dimensions, mass, material, and dimensions of operating surfaces, as well as a range of their adjustment range, clamping force, etc. Additionally, the tables include references of working files of their 3D models. Table "material" contains the information about physical, mechanical, and technological properties, as well as a chemical composition of the manufacturable materials. For comfortable working with this information, all the materials are divided into groups (i.e., ferrous metals and alloys, nonferrous metals and alloys, non-metals).

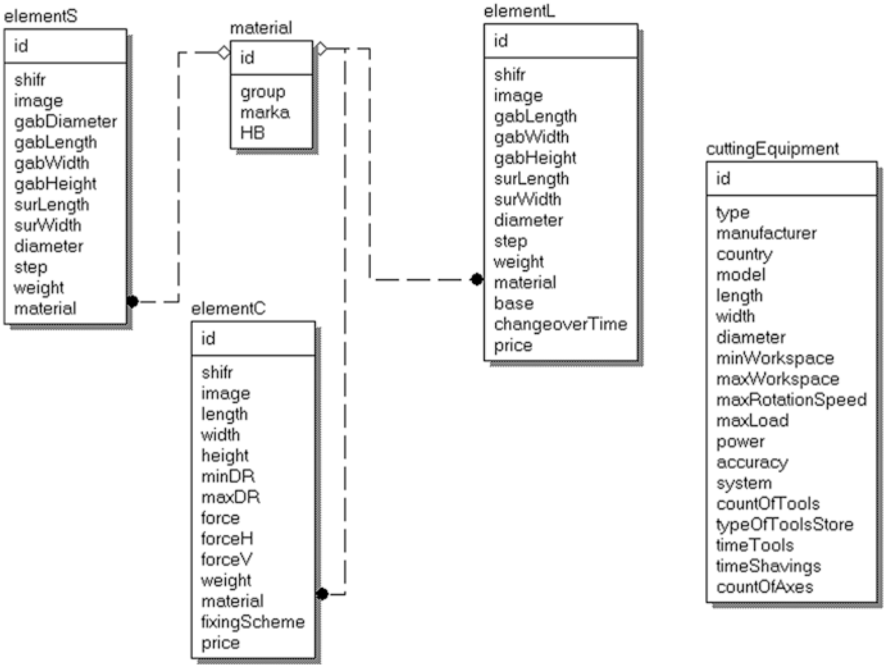

Fig. 11.4 The relation database model

The table “Cutting Tools” contains information about the equipment for drilling-milling-boring machining. All the elements of this library are organized according to the following parameters: the degree of automation, the machine layout, technological capabilities, overall dimensions of the operating space, type and set of the tool shop, spindle speed, power drive capacity, etc. The library also contains information about 1075 vertical and horizontal machine tools of more than 30 leading world manufacturers.

The table “Fixtures” stores information about the typical sets of fixtures, as well as about previously designed projects. In fact, this table is the archive of the design procedures. The physical database model is realized by the open source relational database management system MySQL.

11.4 Results

According to the research work [25], there are several main modules in the CAFD system. These modules directly execute all the operating procedures. One of such module is aimed at organizing of the user’s work with the information system. Previously, the UML model of the further software was built. The use-case diagram is presented in Fig. 11.5 for visual reflecting all the possible options of user’s work with the abovementioned module.

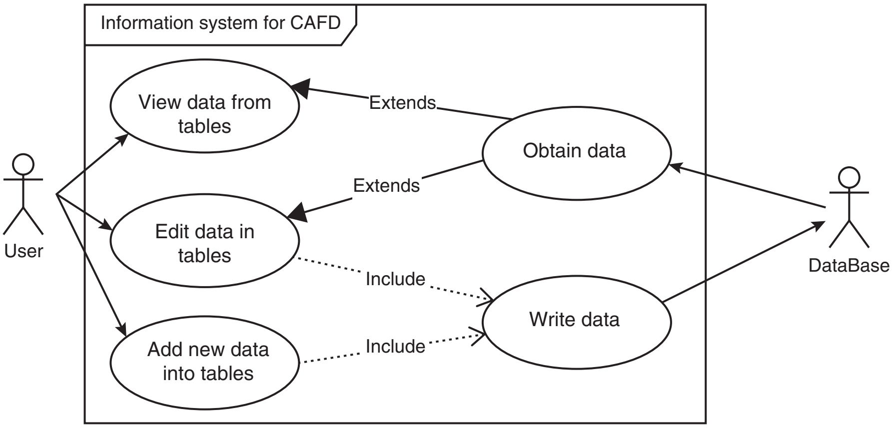

Fig. 11.5 The use-case diagram

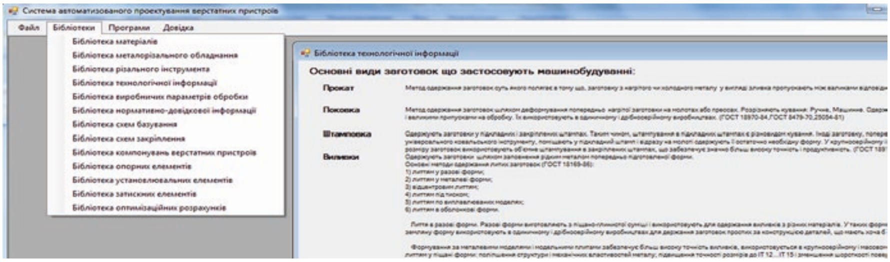

Fig. 11.6 The program window with the normative and methodical information

Due to multifunctionality of the CAFD system, the interface of the design system is made according to the MDI-application technology for ensuring the access to the auxiliary information throughout the operating process. This technology provides the main window, which allows formatting and opening several individual windows at the same time. All these windows are combined in a common working area and guided by the common user menu.

All the work with the elements of information support is realized by the main menu item “Libraries” (Fig. 11.6).

The program modules are used for presenting the normative and methodical information. They generate the typical MS Office window with the related contents. The presentation of the following information is realized using the abovementioned approach, for example:

- the technological information (Fig. 11.6)—about the types of workpieces, types of the heat treatment, classification of the manufacturing operations and steps; the recommended parameters of the size accuracy and the quality of the surfaces;

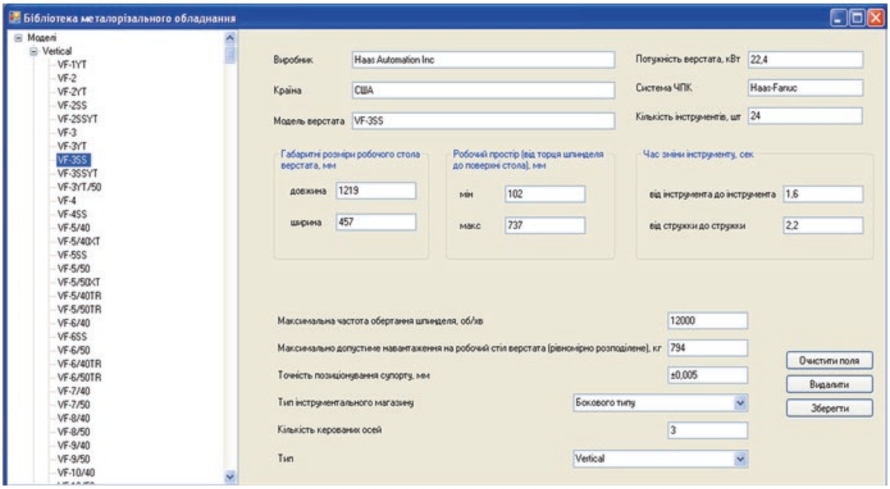

Fig. 11.7 The module “Metal-cutting equipment”

- the manufacturing parameters of the machining—about the type of manufacturing, manufacturing capacity, batch size, level of flexibility, and the level of machining efficiency;
- the locating charts of the workpieces—about the typical locating charts of the prismatic parts, rotational parts (i.e., shafts, shaft-collars, flanges), flat parts, and complex parts (i.e., levers, connecting rods, brackets, cantilevers). According to the library information, it is possible to provide a defined locating of 90% of the workpieces that are machined on the machine tools of the drilling-milling-boring group.

The separate program modules are developed for working with database tables for the purpose to realize the user graphical interface. This allows complementing the libraries conveniently, as well as viewing, editing, or deleting information.

For the convenient work with tables, the program windows contain the navigational menu as a tree-like structure. After choosing the item, its characteristics are displayed in another area of the window, and an appropriate data editing function is proposed (Fig. 11.7). Due to the highly specialized system directed for specialists only, explanations of individual parameters are not provided.

The auxiliary program windows (Fig. 11.8) with the related pictograms appear for working with the database of locating, supporting, and clamping elements [27].

Actions of the user are controlled for the purpose to reduce the mistakes when entering the data in the editing fields. Particularly, selection of one value from the set of possible ones is realized by the drop-down list.

Some values (e.g., material properties) can be filled in only by selecting the required values from the referral directory (Fig. 11.9).

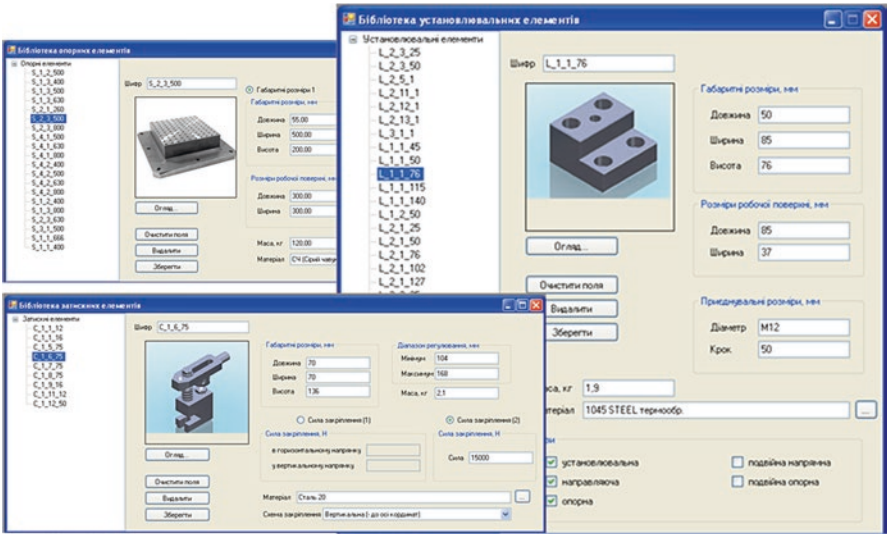

Fig. 11.8 Program window of the fixture functional elements

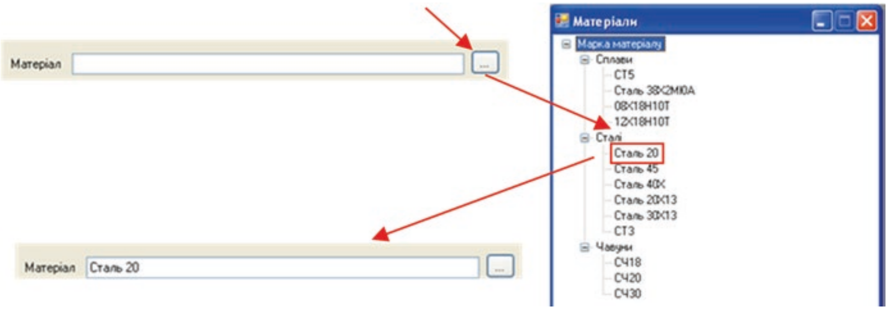

Fig. 11.9 Filling in information from the reference tables

A significant amount of information required for providing calculations is stored in the Microsoft Excel format. The related module “Parser” is developed for simplifying such information in the database. This module allows ensuring automated input of information. The input file (Fig. 11.10) should match the following requirements:

- files should be in the format *.xls;
- the first row should contain the column headers;
- the data for recording into the database should follow the second line;
- the order of columns should match the database fields.

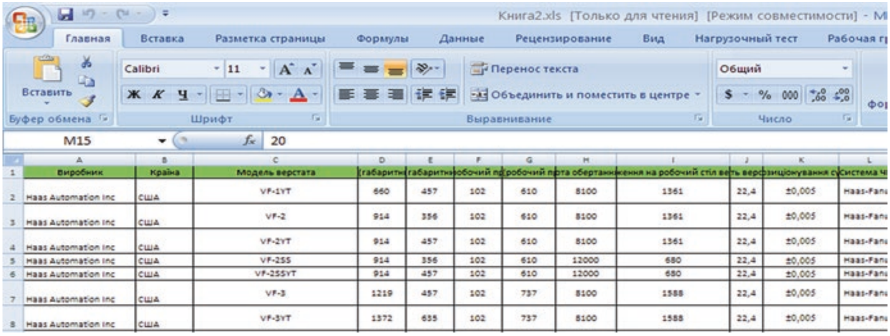

Fig. 11.10 The Excel database of machine tools

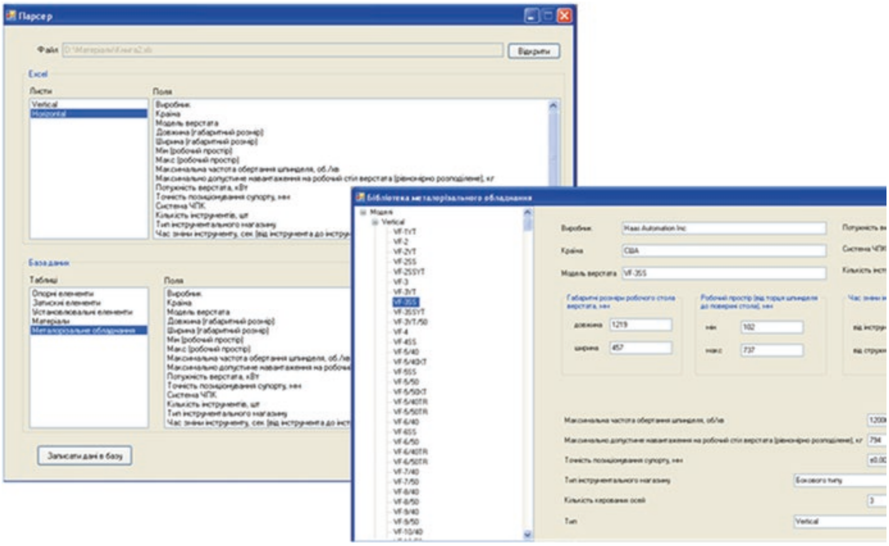

Fig. 11.11 The module "Parser"

Import of the data about machine tools is realized by the module "Parser" (Fig. 11.11).

A user chooses the needed Excel file using the typical dialog box. After that, a list of column headers should be chosen on the selected worksheet ("Fields" of the group "Database"). In the group "Database," the user should select the table, to which the import will be executed. As a result, a list of fields will be displayed. If the list of headers in the group "Excel" does not match the related list of fields, reformatting the input file is needed. In the case of saved lists, it is sufficient to execute the command "Record Data into the Database" to import the data.

11.5 Conclusions

The large amount of information transferred and stored in the CAFD system determines the relevance and importance of the problem of ensuring the effectiveness of information support for the design process. This conclusion emphasizes the main factors that directly impact on the execution time of the design procedure. An engineer as the user of CAFD systems receives convenient and fast access to all the necessary electronic databases within the developed subsystem "CAFD," which is concentrated in a single software application.

Since the database allows accumulating the previous calculation results, the further research will be aimed at organizing the pre-search module for fixture configurations. This approach allows additionally reducing the time for implementation of design procedures.

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Chapter 12
Mathematical Modeling and Numerical Simulation of Fixtures for Fork-Type Parts Manufacturing

Vitalii Ivanov, Ivan Pavlenko, Ivan Kuric, and Mykyta Kosov

12.1 Introduction

The main tasks of fixtures are the precise locating and reliable clamping of workpieces during the machining on the machine tools. Fixtures are an integral part of the closed-loop technological system "machine tool–fixture–cutting tool–workpiece". Fixtures considerably effect on the quality and the cost of final products, as well as productivity and flexibility of production [1, 2]. The statistical data [3, 4] confirmed the importance of fixtures for products manufacturing. Fixture design is complicated and time-consuming process [5, 6]. It is important to find the optimal solution between flexibility and productivity, as well as to ensure the required accuracy [7]. Therefore, fixture requirements were identified and should be considered during design process [8–17]. The problem of fixture design is very urgent and relates to the multidisciplinary tasks on ensuring the stable locating of workpiece in the fixture during the machining process.

12.2 Literature Review

For many years fixture design has been the focus of academic research with significant progress in both theoretical and practical studies.

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Research paper [18] presents the methodology of modeling of the system "fixture–workpiece". In addition, the influence of the previous load from the impact of clamping and cutting forces on the error of the work surface was determined [18]. Friction between elements of the mechanical system "fixture–workpiece" has been researched and have been determined the deformations, which appear in the contact points [19]. The methodology of analysis of stability of the system "fixture–workpiece" has been developed and calculation of the minimum clamping force, required for machining process, has been presented; also, the influence of sequence of workpiece clamping has been researched [20]. The influence of modes of cutting and fixture compliance on the workpiece stability was analytically calculated and researched [21]. The simplified analytical model of the contact interaction between workpiece and clamping elements was developed [22]. The finite element model for determination of the stability of workpiece locating in fixture and the methodology of optimization of the previous loading were developed [23]. The mathematical model of fixture interaction with workpiece and analysis of deterministic positioning of fixture was developed [24]. Many researches in fixture accuracy and analysis of the fixture stability were realized, based on the consideration of 2D problem and introduction of "operative factor," which considers the friction forces [25]. The methodology on determination of points and clamping forces for ensuring the stable locating of workpiece in fixture has been developed [26]. The methodology of control of clamping force considering the contact interaction between workpiece and clamping elements by means of the methods of nonlinear programming was presented [27]. The problem of the temporariness of the stability of fixture locating considering the restriction of the force and direction of its action in the system "fixture–workpiece" has been researched [28]. The influence of material removal on the dynamic state of the system "fixture–workpiece" was considered as opposed to quasistatic approach of predecessors [29]. Moreover, scientific and methodological approach for identification of mathematical models of the mechanical system "fixture–workpiece" using artificial intelligent systems is proposed in paper [30]. Paper [31] focuses on the investigation of the affect that an automated flexible fixture has on the vibrational characteristics of parts in a reconfigurable manufacturing environment, through modeling the modal characteristics of test parts, of differing geometries, for various fixturing setups.

The goal of the proposed work is the mathematical modeling and numerical simulation of the system "fixture–workpiece" based on manufacturing features of the process of locating and clamping of the workpiece in the fixture considering dynamic analysis of the workpiece in fixture under the effect of spatial system of cutting and clamping forces.

12.3 Research Methodology

12.3.1 Mathematical Model

The fixture for multiaxis machining of parts is developed based on the analysis of requirements for fixture designing and fork-type parts manufacturing (Fig. 12.1). The main advantage of the proposed fixture configuration is the possibility of readjusting its functional elements when changing the workpiece dimensions.

The conservative mechanical system including a workpiece and clamped by supports is considered in a local orthogonal coordinate system xyz with the origin in the mass center C. The relative coordinates of the current point B_j, forces F_x^j, F_y^j, F_z^j and moments M_x^j, M_y^j, M_z^j for modeling space movement of a workpiece are presented on the related design scheme (Fig. 12.2).

The displacements x_i, y_i, z_i of the workpiece supporting surfaces in a fixture are determined as static displacement. They can be expressed by geometric dependencies with respect to six independent parameters (degrees of freedom of the workpiece): x, y, z, φ, ψ, θ [32].

All the components of supports displacements are calculated by the following formulas:

$$\begin{aligned} x_i &= x_C - b_i\theta + h_i\phi; \\ y_i &= y_C + l_i\theta + h_i\psi; \\ z_i &= z_C + l_i\phi + b_i\psi, \end{aligned} \quad (12.1)$$

where x_C, y_C, z_C are coordinates of mass center and l_i, b_i, h_i are local longitudinal, transverse, and vertical coordinates.

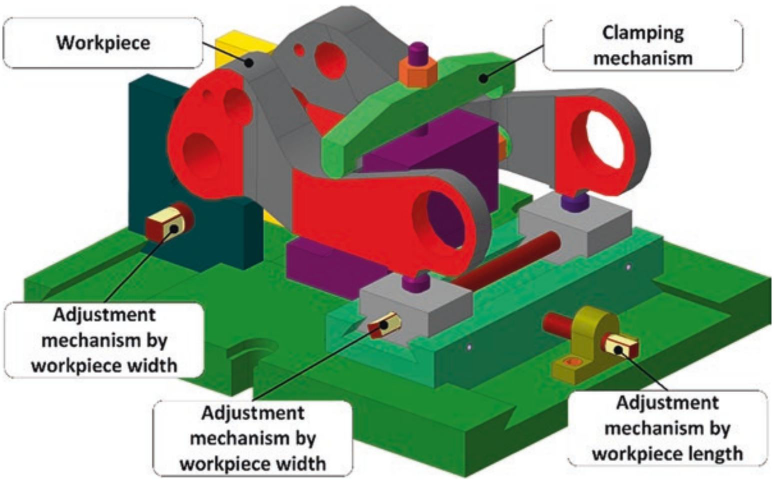

Fig. 12.1 The mechanical system "fixture–workpiece"

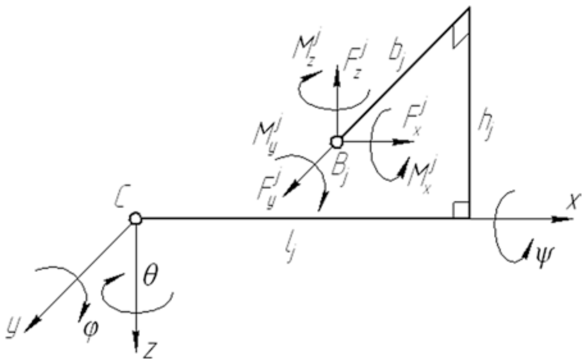

Fig. 12.2 The local coordinate system for modeling spatial movement of the workpiece

The spatial movement of the workpiece in a fixture can be determined by the center-of-mass theorem and the momentum theorem. The related mathematical model of dynamic analysis is realized by the system of 12th order differential equations with respect to the abovementioned independent parameters [33].

Local components of the related dynamic forces F_x, F_y, F_z and moments M_x, M_y, M_z have the following form:

$$
\begin{aligned}
F_x &= -\Sigma k_x^i \left(x_C - b_i\theta + h_i\phi\right);\\
F_y &= -\Sigma k_y^i \left(y_C + l_i\theta + h_i\psi\right);\\
F_z &= -\Sigma k_z^i \left(z_C + l_i\phi + b_i\psi\right);\\
M_x &= -\Sigma\left[k_y^i h_i\left(y_C + l_i\theta + h_i\psi\right) + k_z^i b_i\left(z_C + l_i\phi + b_i\psi\right)\right];\\
M_y &= -\Sigma\left[k_x^i h_i\left(x_C - b_i\theta + h_i\phi\right) + k_z^i l_i\left(z_C + l_i\phi + b_i\psi\right)\right];\\
M_z &= -\Sigma\left[-k_x^i b_i\left(x_C - b_i\theta + h_i\phi\right) + k_y^i l_i\left(y_C + l_i\theta + h_i\psi\right)\right],
\end{aligned}
\tag{12.2}
$$

where m is workpiece mass and J_{Cx}, J_{Cy}, J_{Cz} are central moments of inertia.

12.3.2 Modal Analysis

To prevent a resonance phenomenon during the process of workpiece machining, the oscillation frequency for fixture elements should not coincide with the main frequency of the cutting process. One of the ways to avoid this problem is to set another cutting mode. For this purpose, eigenfrequencies of the mechanical system "fixture–workpiece" are determined using the ANSYS software. As a result, the minimal value of the obtained frequencies is compared with the related frequency during the cutting process.

In the case of zero value of forces and cutting moments, the mathematical model takes the following matrix form:

$$[M]\left\{\ddot{X}_C\right\}+[K]\{X\}=\{0\}, \tag{12.3}$$

where {0} is zero column vector of external impact, {X} is column vector of displacement, [M] is matrix of inertia, [K] is stiffness matrix, the components of which depend on the contact stiffness coefficients k_x^i, k_y^i, k_z^i of supporting surfaces:

$$\begin{aligned}
&k_{xx}=\Sigma k_x^i;\ k_{yy}=\Sigma k_y^i;\ k_{zz}=\Sigma k_z^i;\ k_{\psi\psi}=\Sigma\left(k_y^i h_i^2+k_z^i b_i^2\right);\\
&k_{\phi\phi}=\Sigma\left(k_x^i h_i^2+k_z^i l_i^2\right);\ k_{\theta\theta}=\Sigma\left(k_x^i b_i^2+k_y^i l_i^2\right);\ k_{x\phi}=\Sigma k_x^i h_i;\\
&k_{x\theta}=\Sigma k_x^i b_i;\ k_{y\psi}=\Sigma k_y^i h_i;\ k_{y\theta}=\Sigma k_y^i l_i;\ k_{z\psi}=\Sigma k_z^i b_i;\\
&k_{z\phi}=\Sigma k_z^i l_i;\ k_{\psi\phi}=\Sigma k_z^i l_i b_i;\ k_{\psi\theta}=\Sigma k_y^i l_i h_i;\ k_{\phi\theta}=\Sigma k_x^i b_i h_i.
\end{aligned} \tag{12.4}$$

Six eigenfrequencies of the mechanical system “fixture–workpiece” are determined as natural values of the matrix of dynamic stiffness, which is equal to the roots of the following polynomial equation:

$$\left|[K]-\omega^2[M]\right|=0. \tag{12.5}$$

12.3.3 Harmonic Analysis

Spatial movement of the workpiece in a fixture as a 6-degrees-of-freedom system is determined analytically by the following matrix form:

$$[M]\left\{\ddot{X}_C\right\}+[K]\{X\}=\{F\}, \tag{12.6}$$

where {X} is column vector of displacements and {F} is column vector of external dynamic impact.

Monoharmonic external impact can be described by the expression $\{F\} = \{F_a\}\cdot\sin\omega t$, where $\{F_a\}$ is column vector of dynamic amplitudes; $\omega = \omega_0\cdot z$—frequency as a product of the spindle’s rotation frequency and a number z of teeth of the operating cutting tool.

The general solution of the Eq. (12.6) can be presented as a column vector $\{X_a\}$ of displacement amplitudes of center of weight and rotation angles around the coordinate axes:

$$\{X_a\}=\left([K]-\omega^2[M]\right)^{-1}\{F_a\}. \tag{12.7}$$

The achieved dependence of $\{X_a\}$ components on the cutting frequency ω determines the amplitude-frequency response characteristics of the considered mechanical system “fixture–workpiece.”

12.4 Results

12.4.1 Modal Analysis

The objects of the numerical simulation are free and forced oscillations of the mechanical system “fixture–workpiece”. The fixture has the adjustment mechanisms for ensuring its readjustment when changing the object of machining. In this case, the workpiece needs to be machined from different sides.

The results of modal analysis for the first eigenfrequency are presented in Fig. 12.3 and allow detuning from a resonance. The related data is summarized in Table 12.1.

Additionally, the abovementioned data allows concluding that a fixture for the proposed manufacturing process is less compliant in comparison with the same fixture for the typical manufacturing process, since the first eigenfrequency increases in 1.64 times.

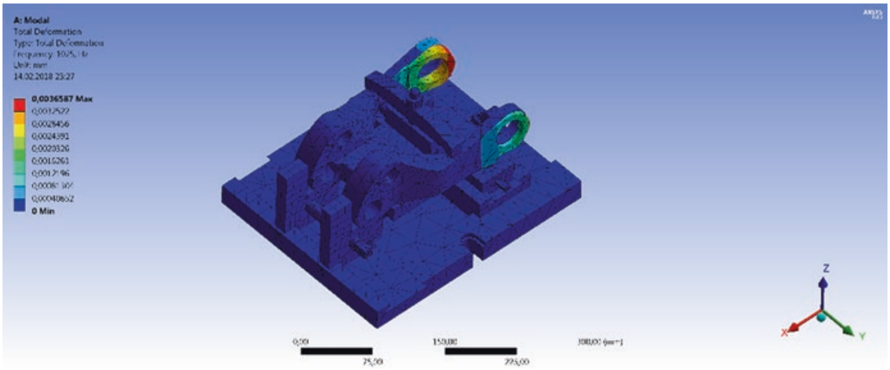

Fig. 12.3 The results of modal analysis

Table 12.1 Comparative analysis of eigenfrequencies for the mechanical system “fixture–workpiece” in the case of fork-type parts machining, Hz

Fixture design	Eigenfrequency			Cutting frequency
	1st	2nd	3rd	
Typical manufacturing process	625	836	1550	1271
Multiaxis manufacturing process	1025	1055	1513	1271

12.4.2 Harmonic Analysis

Determining the oscillation amplitudes for the machined surfaces under the deviation of cutting forces and moments allows ensuring the sufficient rigidity of the mechanical system "fixture–workpiece". For this purpose, the following objectives are stated for the case of fork-type parts machining:

1. obtaining the amplitude-frequency response under the most loaded operating step,
2. evaluating the resonance frequency and comparing with the related cutting frequency.

Harmonic analysis is realized by using the ANSYS software. Amplitudes of the dynamic components of cutting forces are equal 20% from their nominal values. The proposed model takes into account the Coulomb friction between the contact surfaces [34], which have approximately the same roughness Ra = 1.6 μm with the friction coefficient 0.1. A range of oscillation frequencies is chosen for the reason of providing coverage of the first three eigenfrequencies obtained above. So, the maximum oscillating frequency is equal to 1550 Hz.

The amplitude-frequency response is obtained (Fig. 12.4), as well as pre- and under resonance modes are determined. For ensuring equal conditions, the comparison analysis is carried out for displacements under the resonance frequency. The maximum displacement for the proposed fixture design is equal to 25 μm. The result of harmonic analysis is presented in Fig. 12.4, and the related numerical simulation data is summarized in Table 12.2.

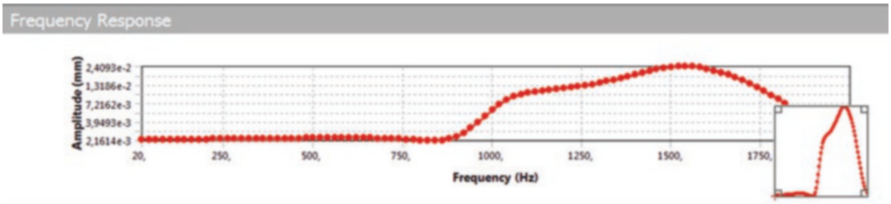

Fig. 12.4 The amplitude-frequency response for the fixture design while drilling holes in fork plugs

Table 12.2 The results of numerical simulation for the fixture design while drilling holes in fork plugs

Fixture design	Nominal cutting force, N	Amplitude of the dynamic force, N	Maximum displacement, μm
Typical manufacturing process	5398	1079	93
Multiaxis manufacturing process	5398	1079	25

12.5 Conclusions

In the research of recent challenges in fixture design for manufacturing complex parts, the existing approaches for designing CAx systems are systematized and generalized. As a result, a brand-new approach is developed based on a comprehensive analysis of free and forced oscillations of the mechanical system "fixture–workpiece" under the impact of clamping and cutting forces.

The mathematical model of free and forced oscillations for research of the dynamic states of the comprehensive mechanical system is proposed. It is proved on the example of fork-type parts considering contact stiffness of functional elements, required clamping forces, and dynamic components of cutting forces and moments. This model allows determining natural frequencies of free oscillations with the aim of detuning from a resonance. It should be noted that the first eigenfrequency 1025 Hz for the proposed manufacturing process is 1.64 times more than the same frequency for the typical manufacturing process. Consequently, the dynamic stiffness of the new design is significantly increased, and required deturning 20% from a resonance frequency 1271 Hz is ensured.

The research of forced oscillations of the proposed system under the impact of dynamic forces and cutting moments is presented. As a result, the amplitude-frequency response is obtained using the ANSYS software. It should be noted that the maximum displacement 25 μm does not exceed all the required tolerances and related manufacturing errors.

Further research will be aimed at developing the research methodology and related engineering approach for estimating parameters of the proposed mathematical model by the results of numerical simulation and experimental data using both of a linear regression procedure and a nonlinear regression analysis by means of artificial intelligent systems.

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