Searching and Selection of a Flexible Manufacturing System by Means of Frame Model

J. F. Mammadov, K. S. Abdullaev, U. H. Agaev, I. R. Aliev, and G. G. Huseynova

Abstract In accordance with the topic of the chapter, to ensure the management and operation of archives of design work, a comparative analysis of information support algorithms was carried out, allowing you to choose flexible manufacturing systems (FMS), their standard elements, production modules, layout schemes and a set of information about their parameters or location of documents. The task was set and the model for creating algorithmic support based on the frame modeling for the effective search and selection of FMS, its production modules, and active elements by the scope of production and the purpose of each technical unit was implemented. To ensure the reliable functioning of the FMS automatic control system, an algorithm is proposed for the search for sensors based on frame slots and the values of the achievable positioning error of industrial robots and technological equipment. An algorithm for searching for sensors and controlling the active elements of the FMS production module is proposed. The software of an expert system of a frame type with fuzzy control of the shaft processing of a cylindrical gearbox for landing gear and bearings on a lathe in a flexible manufacturing module has been developed.

Keywords Frame modeling · Flexible manufacturing system · Search and selection algorithm · Frame slot · Graph diagram · Expert program

1 Introduction

The economic growth of developing countries largely depends on the introduction of industries with the most advanced technologies for automation and management into their industries. FMS is one of such innovative systems that ensure high-quality production of products for various purposes using flexible automated control technologies. The use of a sufficiently large number of enterprises in various fields of industry, interconnected corporations, and technology parks, due to the lack of their

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A. G. Kravets et al. (eds.), *Cyber-Physical Systems: Modelling and Intelligent Control*, Studies in Systems, Decision and Control 338,
https://doi.org/10.1007/978-3-030-66077-2_11

global information support, to some extent complicates the process of searching and selecting similar FMS projects, especially at the initial stages of their development.

Comparative analysis of existing methods for searching documents for FMS projects [1–3], pp. 123–210 showed that due to the versatility and complexity of such technical systems, difficulties arise with the correct selection of its technological equipment, industrial robots, manipulators, automated system of control (ASC) and their layout. In these works, the process of searching and selecting the active FMS elements is carried out by the user intuitively due to the accumulated experience in this area. For information retrieval, separate algorithms are used using production models [4], pp. 340–412 which do not provide an accurate search and selection of technical units for different applications because of the impossibility of a detailed description of the design object and the use of the number of products and, accordingly, the use of system memory. In this regard, the consideration of the creation of an algorithm for the automated search and selection of active FMS elements using the frame model, which provides step-by-step structural modeling depending on the field of application, is a scientifically relevant problem.

The purpose of this chapter is to develop algorithmic support based on the frame model for information retrieval and selection of FMS, its technical units, and the control system per the process flow diagram.

To achieve the goal, the following issues were identified:

1. Development of a frame modeling algorithm for the search and logical selection of such an FMS for its further design.
2. Creating an FMS search scheme, its equipment, layout, and ASC based on a graph—model frame diagram.
3. Construction of the layout diagram of the FMS in accordance with the results of the information search algorithm.
4. Creation of an algorithm for a reliable search for FMS sensors based on the frame model.
5. Creating a control algorithm using the example of FMS production module using logical transition conditions.
6. Software development of expert knowledge representation for the search, selection, and process control of a flexible manufacturing module for the manufacture of shafts of a cylindrical reduction tool.

2 Development of an Algorithm for the Frame Model for the Search and Selection of FMS, Its Control

To create an algorithm for searching and selecting complex technical systems, like a flexible production system, an intelligent method based on a modeling frame is used. The frame model is presented in the form of the following construction [5]:

$$f = [\langle r1,\ v1\rangle,\ \langle r2,\ v2\rangle,\ \ldots,\ \langle rn,\ vn\rangle] \tag{1}$$

where f is the name of the frame; *ri* is the name of the slot; *vi* is the value of the slot. The names of other frames act as the values of the slots, which provide a link between the frames. The name of the frame (proto frame) is selected for the search keyword, which is written in the form:

$$\text{fkc} \rightarrow \ll \text{FMS} \gg \tag{2}$$

In order to carry out a reliable search and exact selection of the design object (GPS using the example of a mechanical assembly shop), it is necessary to enter the name and value of the slot <*rj*, *vj*> in the form, respectively [6]:

$$\begin{aligned} & f_{KC} = [\langle r_1 \rightarrow \text{Application field}, v_{1j} \in \{v_{11}, v_{12}, \ldots, v_{14}\}\rangle, \\ & \langle r_2 \rightarrow \text{Production}, v_{2i} \rightarrow \{v_{21}, v_{22}, v_{23}\}\rangle \\ & \langle r_3 \rightarrow \text{ Equipment}, v_{3k} \in \{v_{31}, v_{32}, \ldots, v_{37}\}\rangle \\ & \langle r_4 \rightarrow \text{ FMS composes structure}, v_{4i} \in \{v_{41}, v_{42}, v_{43}\}\rangle \\ & \langle r_5 \rightarrow \text{ Control system of FMS}, v_{5i} \in \{v_{51}, v_{52}, v_{53}\}\rangle], \end{aligned} \tag{3}$$

where v11 is the automotive industry; v12—mechanical engineering; v13—instrument making; v14—metallurgy; v21—car; v22—truck; v23—electric car; v31—lathe; v32-milled machine; v33—drilling machine; v34—grinding machine; v35—bending machine; v36—welding industrial robot; v37—loading industrial robot; v41—sequential layout; v42—round layout; v43—parallel layout; v51—ASC based on SCADA TRACE MODE; v52—ASC based on microprocessor control system (PLC Network); v53—ASC based on PLC Simatic.

Based on the proposed proto-frame, from the established values of the *ri* slots, a search engine for FMS and its modules for the manufacture of cars of various models is compiled with a further selection of the layout of flexible manufacturing modules, technological equipment, industrial robots and ASC (Fig. 1).

As can be seen from Fig. 1, the search and selection of FMS, its control system is carried out in stages, starting by entering the keywords as in expression (2). From the expression (3), the names of the slots *ri* are selected which are converted into frame names (f21, f3k, f43, f51).

As can be seen from Fig. 1, the search and selection of FMS, its control system is carried out in stages, starting by entering the keywords as in expression (2). From the expression (3), the names of the slots r_i are selected which are converted into frame names (f21, f3k, f43, f51).

Based on frames f21, f3k, f43, f51, the search and selection of FMS, its control systems for the production of passenger cars, with all equipment, with their parallel layout and an automated control system based on SCADA TRACE MODE are implemented.

The frame model with the conclusions of the phased choice of the scope of production, the type of products, types of technological equipment, industrial robots, the

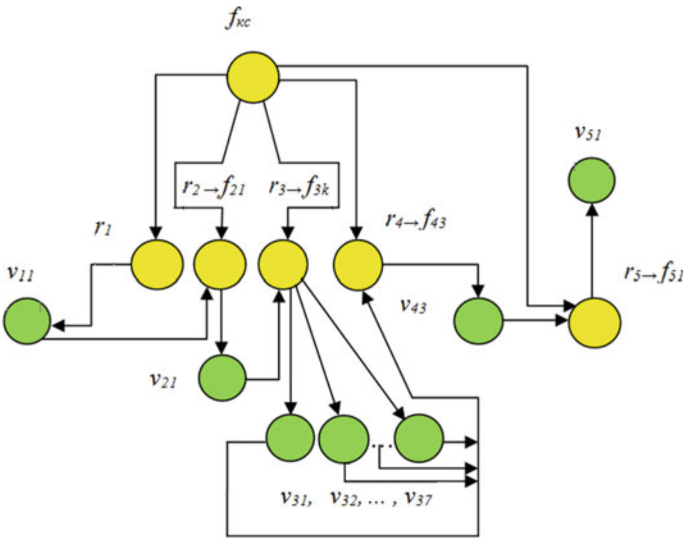

Fig. 1 The scheme of searching and selection of FMS, its equipment and ASC

layout of the FMS, and the automated control system is written in the form of logical expressions as follows:

```
If < r1, v11 > then < r2, v21,
where r2 → f21 >;
If < r2, v21 > then < r3, v3i,
where r3 → f3k >;
```

$$\exists \text{ v3k} \in \{v_{31}, v_{32}, \ldots, v_{37}\}\rangle,$$

```
If < r3, v3k > then < r4, v43,
where r4 → f43 >;
If < r4, v43 > then < r5, v51,
where r5 → f51 >.
```

Based on the above algorithm, the flexible manufacturing module is formed with a parallel layout scheme, standard equipment, and an automated control system based on SCADA TRACE MODE [7] (Fig. 2).

The issue of choosing a technical solution for automated FMS control based on TRACE MODE is implemented in four stages: the choice of peripheral system hardware and network equipment; organization of the structure of information flows in the system; definition of information traffic regulations, setting up TRACE MODE servers [8]. The structure of information flows in the ASC of FMS should provide the necessary level of reliability and productivity.

The process of selecting the elements of the FMS control and monitoring system is formed based on the proposed layout diagram of the FMS production sites and their automation scheme. Based on the requirements for the accuracy of positioning of the handling facility on the working areas of the FMS production line, the total

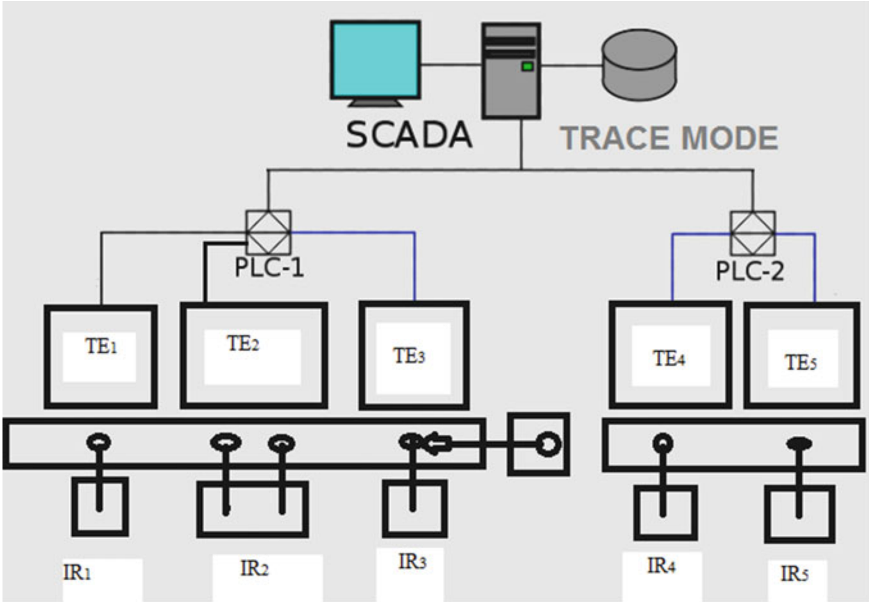

Fig. 2 Composes layout of FMS with ASC based on SCADA TRACE MODE

positioning error is determined. In this case, the error in the installation of the object in the equipment adaptation consists of two components: the error of the mismatch of the center of the shape of the part with a certain center in the equipment and the orientation error in the angle relative to some axis.

3 Creation of an Algorithm for Selecting Sensors and a Control Algorithm for FMS Manufacturing Module

The characteristics of manipulation objects in the FMS technological route influence the choice of the type and structure of sensing systems, the design of the actuator, and the functions of industrial robots in the flexible manufacturing module. The characteristics of the manipulation object determine the type of working zone of the active FMS elements.

Based on the assessment of the achievable positioning error, the sensors for the automatic control system of FMS are selected [9]:

$$\frac{S_i k_\Delta}{D_n} \leq \Delta_i \quad i = \overline{1, n}, \tag{4}$$

where S_i is the movement of the degree of mobility; $k_\Delta = 1.5, \ldots, 3$—coefficient taking into account the quality of the measuring circuits of the control system; Δ_i—positioning error of the robot, with three degrees of mobility, functioning in a flexible manufacturing module. The positioning error value is selected from the directory; D_n is the number of discrete inductive sensors measuring and angular displacement of an industrial robot.

In accordance with expressions (1) and (4), the values of the slots of the frame model for searching and selecting the elements of the FMS control system in the following form are determined:

FASC FMS $= [\langle \text{r6} \rightarrow \text{application object, v6j} \in \{ \text{v}_{11}, \text{v}_{12}, \ldots, \text{v}_{14}\} \{\text{v6j, v6j}, \ldots, \text{v611} \}\rangle$, where $j = 11$—the quantity of technological equipment and industrial robots in FMS.

$$\langle r7 \rightarrow Si,\ v7j \in \{v_{11}, v_{12}, \ldots, v_{14}\}, \{v7j,\ v7j, \ldots,\ v711\}\rangle,$$

where for each active element's movement where the degree of mobility for each active element of FMS is taken into account.

$$\langle r8 \rightarrow k\Delta,\ v8j \in \{v_{11}, v_{12}, \ldots, v_{14}\}, \{v8j,\ v8j, \ldots,\ v811\}\rangle,$$

where the quality factor of the measuring circuits of the control system is taken into account for all active FMS elements.

$$\langle r9 \rightarrow \Delta i,\ v9j \in \{v_{11}, v_{12}, \ldots, v_{14}\}, \{v9j,\ v9j, \ldots,\ v96\}\rangle,$$

where the positioning error is taken into account for industrial robots of FMS. $j = 6$ is the number of industrial robots in the FMS.

$$\langle r10 \rightarrow \Delta n, v10j \in \{v_{11}, v_{12}, \ldots, v_{14}\}, \{v10j,\ v10j, \ldots, v106\}\rangle,$$

where the discrete number of the inductive sensor for measuring an angular displacement is taken into account for each industrial robot of FMS.

Based on the algorithm for searching for types of FMS sensors, an appropriate sensor is selected for particular equipment and industrial robot, which ensures reliable operation of the FMS automatic control system as a whole.

The database of sensors of the control system for active FMS elements is presented in the form of a recursive procedure, where the basis is the active FMS elements, their technologically functional characteristics, and parameters (Table 1) [10].

To select the parameter values from the database, a request is made from the expert system [11] for the designated symbols of the sensors in the following form:

$$|\,? - \text{ sensor (Sfw, Parameter). Parameter } = \Delta 1.$$

Table 1 Technologically functional characteristics

#	Place of installation	Symbol	Fixing
Sensor	Gripper of IR	S_{gp_i}	The availability of workpieces
Sensor	Hand of IR	S_{u_i}	Up
Sensor	Hand of IR	S_{b_i}	Backward
Sensor	Hand of IR	S_{t_i}	Angular
Sensor	Hand of IR	S_{fw_i}	Forward
Sensor	Hand of IR	S_{d_i}	Down
Sensor	Technology equipment TE_i	S_{a_i}	The availability of workpieces
Sensor	Hand of IR	S_{up_i}	Up
Sensor	Hand of IR	S_{b_i}	Backward

where Δl is the movement of the hand of the industrial robot (IRi) forward or backward along the X or Y axis of the three-dimensional coordinate axis; Δh is the movement of the hand of IR up or down along the Z-axis of the three-dimensional coordinate axis; $\Delta\varphi$—the angular movement of IR hand around the Z-axis of the three-dimensional coordinate axis.

To determine other parameters from the database, similar queries are performed in the same way.

The next step in the creation of an automated FMS control system is the development of its control algorithm, which characterizes the logical conditions-transitions depending on the production cycle.

To develop a control algorithm, a step-by-step scheme of FMS automation is analyzed; initial parameters are set that characterize the displacements of the kinematic links IR and equipment, the workpiece numbers, the names of sensory and actuating elements in accordance with the functional purpose; Based on the recursive procedure [12], a control model for the manufacturing module is compiled.

The FMS control system functions as follows: information is received by the control microprocessor system about fixing the availability of the workpiece at the initial position of the automated transport system (ATS_i); sensory and executive organs IR are triggered; the technological functions of the servicing industrial robot IR begin, which ensures safe movement along with the established generalized coordinates, loading (the clamping force of the workpiece should not exceed the established norm to prevent rejection on its surface) and unloading the workpiece on equipment; Further, information on the completion of technological operations is transmitted to the control system of FMS which in turn, after processing current information from the device to determine product defects, sends a command to the executive body of the industrial robot to install the finished product or to exchange for finished products, or on a table for defective products [13].

In this case, the coordinates of the active elements are set according to previously de-fined parameters from Table 1.

As input data for the development of a control algorithm, types of sensors, actuators, and blanks are set. The generalized form of the FMS control algorithm is represented in the form of productions with true expressions and a logical consequence as follows [14]:

% variable names:

% AW_i—workpieces

% S_i—sensors with functional values

% A_i—actuators with functional purposes

% true expression (S_i) logical consequence (A_i) AW_i

if_then ($S^1{}_1 \wedge S^1{}_2 \wedge \ldots \wedge S^1{}_n \Rightarrow A^1{}_1 \wedge A^1{}_2 \wedge \ldots \wedge A^1{}_n$ *AW_i*)

if_then ($S^2{}_{1i} \wedge S^2{}_{2i} \wedge \ldots \wedge S^2{}_k \Rightarrow A^2{}_{1i} \wedge A^2{}_{2i} \wedge \ldots \wedge A^2{}_{ni}$ *AW_i*)

...

...

...

If_then ($S^m{}_{1i} \wedge S^m{}_{2i} \wedge \ldots \wedge S^m{}_k \Rightarrow A^m{}_{1i} \wedge A^m{}_{2i} \wedge \ldots \wedge A^m{}_{ni}$*AW_i*).

The developed control algorithm for FMS sections allows you to analyze and describe the operating conditions of the actuator of each active element; synthesize control actions, programmatically automatically analyze current information about the state of the object, ensure maximum speed in management.

4 Creating Software for Searching and Selecting a FMS Project

To search and select FMS by region, types of products, types of equipment, and layout, we set the initial software window of the expert system [15]. The study of intelligent systems showed that in order to obtain reliable information about the process of automated search and the selection of complex technical systems like FMS, the development of an expert software environment based on ExpWin is required.

For this, on the basis of the frame method of modeling the search process and the selection of FMS, the key data are introduced (Fig. 3). In this case, the initial data are used according to expression (3).

When creating a new frame, at first the frame type is initially determined: "Class", then a new slot is added by entering the name of the new slot in the "New slot name" field and activating the "Add slot". The name of the new slot "Flexible manufacturing module (FMM)" is presented as one of the production units of FMS. It appears in the "Slots" field. The slot value, in this case, corresponds to the FMM for the production of machine tools [16].

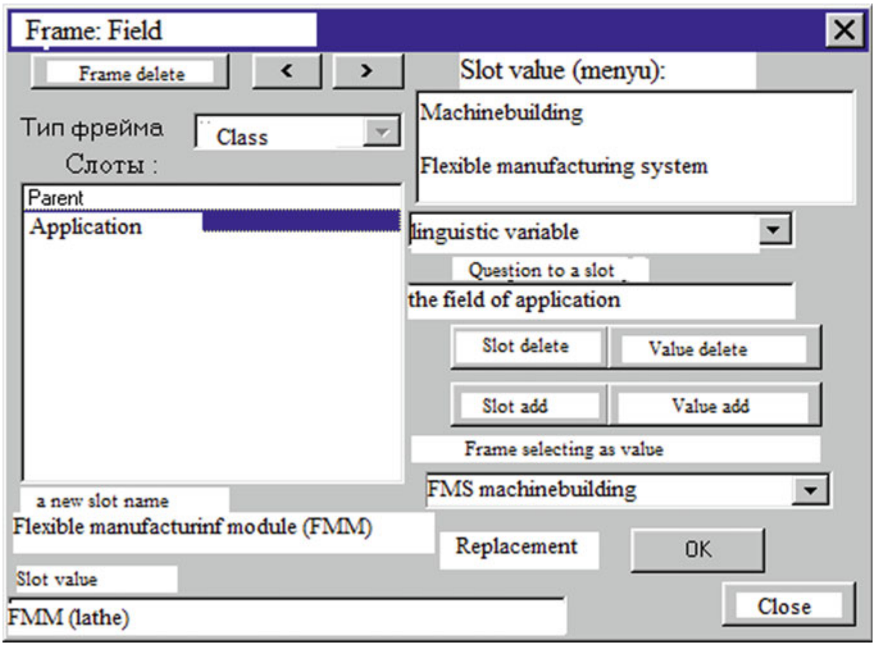

Fig. 3 Software window Frame-selection of FMS by field of application

For the selected slot, we introduce some parameters: the type of slot, the question of the slot, the slot values (Engineering, Flexible manufacturing system). This type of slot is expressed by a linguistic variable which is determined by choosing from the list “FMS in the field of mechanical engineering”. As a slot question, what is the scope? in the “Question to slot” field. The slot values are sequentially entered and added to the field “Slot values Machine-building, Flexible manufacturing system (FMM machine tool (CNC lathe)” using “Add value” [17]. To set the frame name as the slot value from the knowledge base there is a field “Select a frame as a name” After the creation of a new frame, the data is entered into the knowledge base.

When editing a frame, the ability to change the type of frame is blocked. To change any parameters of any of the slots, it is necessary to separate the name of the slot or its value, then in the corresponding field enter the new value of the parameter and make “Replace”. You can add a new slot to an existing frame. In this case, the sequence of actions does not differ from that in the case of creating a new one.

The knowledge base contains a set of frames and production rules for the automated search, selection, and design of the FMS production module. The format of the external representation of the knowledge base for the global search, selection, and design of FMS is presented in the form of the following software procedures [18]:

```
TITLE = <the name of expert system - searching and selecting FMM for
FMS>
```

```
COMPANY = <enterprises name - FMM machine-building>
FRAME // frame <description of frame>
An example of knowledge bases:
TITLE = to select a method of knowledge bases presence FRAME =
purpose
a method of knowledge bases presence: ()
ENDF FRAME = Type
The solved tasks: (Computing select, searching and design of FMS)
ENDF FRAME = The field
Application [What is the field of application?]: (FMS of machine-
building)
ENDF FRAME = Quantity
Number of rules in the knowledge base (numerical): ()
Number of objects in the knowledge base (numerical): ()
ENDF FRAME = Action
Message: ()
ENDF RULE 1
> (Quantity. Number of objects in the knowledge bases; 120)
< (Quantity. Number of objects in the knowledge bases; 150)
< (Quantity. Number of objects in the knowledge bases; 90)
DO = (Type. The solved tasks; computing searching and selecting FMM
for FMS) 210
ENDR RULE 2
> (Quantity. Number of objects in the knowledge bases; 210)
> (Quantity. Number of objects in the knowledge bases; 120)
DO = (Type. The solved tasks; computing searching, selecting and
design) 210
ENDR RULE 3
= (The field. Application; machine-building FMS)
= (Type. The solved tasks; computing searching and selecting)
DO = (A method of knowledge presence; The rules-productions with
fuzzy of knowledge presence) 180
ENDR RULE 4
= (The field. Application; machine tool of FMM)
= (Type. The solved tasks; computing searching and selecting of
equipments for FMM)
DO
= (a method of knowledge presence; Frames) 210
= (A method of knowledge presence; Rules-productions with fuzzy
knowledge presence) 140
= (a method of knowledge presence; Semantically nets) 140
MS (Action. Message; a rule proven 8) ENDR.
```

The knowledge base consists of two parts: constant and variable. The variable part of the knowledge base is represented by the database and consists of facts obtained as a result of inference. The facts in the database are not permanent. Their number and value depend on the process and the results of the logical conclusion [19].

When working with this program shell, frames and production rules that were in a file with the *klb extension remain unchanged. The facts that were in the file with the *dtb extension can change in the process of inference, i.e. appear, be deleted, or change their meaning as a result of working out production rules or dialogue with the user.

The format for the external presentation of frames for automated search and selection of FMM for FMS is implemented according to the following algorithm:

```
FRAME (<frame type>) = <frame name - machine-building FMS>
PARENT: <frame name-ГПМ mechanical as-sembly >
<slot name 1 (manufactured product)> (<slot type (linguistically
variable)>) [<slot question (what is a product type)>?] {<slot
comment (*.txt)>}:
(<value 1 (spur gear)>); (<value 2 (body)>); (<value 2 (shaft)>); …;
(<value k (helical gear)>)
<slot name 2 (equipment)> (<slot type>) [<what is an equipment>?]
{<slot comment слота (*.txt), (*.jpeg)>}:
(<value 1 (lathe)>);
(<value 2 (milling machine)>);
(<value 3 (drilling machine) >);
(<value 4 (grinding machine)>);
(<value 5 (industrial robot) >);
……
<slot name 3 (computing system of control (ASC))> (<slot type
(linguistically variable ))>) [<slot question (what is ASC)>?]
{<slot comment (*.txt), (*.jpeg), (*.dtb)>}:
(<value 1 (PLC)>);
(<value 2 (positioning sensor)>);
(<sensor 3 (displacement sensor)>);
(<value 4 (executive mechanism>)
ENDF
```

When forming a knowledge base for searching and selecting FMM from a flexible manufacturing system, linguistic variables are used as slots when describing fuzzy concepts. The linguistic variable allows you to set both the symbolic and numerical values of the slot of the expert program for fuzzy conclusions of the rules of the process of controlling the choice and design of FMS, its automated control system, and quality control of products [20].

A linguistic variable has one or more symbolic values. Each symbolic value is assigned a membership function, which determines the relationship between the numerical value of the linguistic variable and the reliability coefficient for a given numerical value (corresponding to the symbolic value). Each symbolic value of a linguistic variable has its membership function. The membership function is defined on a segment of the metric scale, the same for all symbolic values of the linguistic variable.

The description of linguistic variables is stored in a text file (*.lvd—Linguistic Variable Description). The first part of the file name must correspond to the names of files containing the knowledge base and database (*.klb and *.dtb). Format of the external representation of a linguistic variable [21]:

```
<Number of linguistic variables>
<Name of linguistic variable 1 (manufactured products - shaft of a
cylindrical gearbox)>
<Lower value of the border of the metric scale
below minimum shaft tolerance
Ø80-0.040.06 f7; eS=40 mkn; ei=-60 mkn for landing gear and bearing
Ø80-0.03-0.06 f7; eS=30 mkn; ei=60 mkn for landing gear and bearing
Ø80-0.020.06 f7; eS=20 mkn; ei=-60 mkn for landing gear and bearing
<Lower limit of the metric scale
```

```
minimum shaft tolerance
Ø80-0.02-0.04 f7; eS=20 mkn; ei=40 mkn for landing gear and bearing
Ø80-0.01-0.04 f7; eS=10 mkn; ei=40 mkn for landing gear and bearing
Ø80-0.000.04 f7; eS=0 mkn; ei=-40 mkn for landing gear and bearing
<Middle limit of the metric scale
normal shaft tolerance
Ø80-0.020.06 f7; eS=20 mkn; ei=-60 mkn for landing gear and bearing
Ø80-0.020.04 f7; eS=20 mkn; ei=-40 mkn for landing gear and bearing
Ø80-0.03-0.06 f7; eS=30 mkn; ei=60 mkn for landing gear and bearing
<Upper limit of the metric scale
maximal shaft tolerance
Ø800.030.00 f7; eS=30 mkn; ei=0 mkn for
normal shaft tolerance
Ø80-0.040.06 f7; eS=40 mkn; ei=-60 mkn for
normal shaft tolerance
Ø800.06-0.033 f7; eS=60 mkn; ei=33 mkn for
normal shaft tolerance
```

For providing a work regime on the determination of shaft by means of linguistical terms, the following expression will write as [21]:

$Ø_1$ → machine is not by a work status ($Ø80^{-0.04}{}_{0.06}$ $Ø80^{-0.03}{}_{-0.06}$ $Ø80^{-0.02}{}_{0.06}$ (clearance and landing));

$Ø_2$ → machine is by a work status with minimal clearance and landing.

($Ø80^{-0.02}{}_{-0.04}$ $Ø80^{-0.01}{}_{-0.04}$ $Ø80^{-0.00}{}_{0.04}$);

$Ø_3$ → machine is by a work status with normal clearance and landing.

($Ø80^{-0.02}{}_{0.06}$ $Ø80^{-0.02}{}_{0.04}$ $Ø80^{-0.03}{}_{-0.06}$);

$Ø_4$ → machine is by a work status with maximal clearance and landing.

($Ø80^{0.03}{}_{0.00}$ $Ø80^{-0.04}{}_{0.06}$ $Ø80^{0.06}{}_{-0.033}$).

In accordance with the created linguistic terms, a control algorithm for processing the shaft with acceptable landing gear and bearing is created:

```
IF «gear and bearing fit
below the minimum shaft tolerance»;
THEN Ø1 «the machine is not in working condition
(Ø80-0.040.06 Ø80-0.03-0.06 Ø80-0.020.06
(clearance and landing))».
IF «landing gear and bearing with
minimal shaft tolerance»;
THEN Ø2 «the machine is in working condi-tion
(Ø80-0.02-0.04 Ø80-0.01-0.04 Ø80-0.000.04
(clearance and landing));
IF «gear and bearing seating with
normal shaft tolerance»;
THEN Ø3 «the machine is in working condi-tion
(Ø80-0.020.06 Ø80-0.020.04 Ø80-0.03-0.06
(clearance and landing));
IF «landing gear and bearing with
maximal shaft tolerance»;
```

```
THEN Ø4 «the machine is in working condi-tion
n(Ø800.030.00 Ø80-0.040.06 Ø800.06-0.033
(clearance and landing)).
```

5 Conclusion

This algorithm allows creating an expert software environment that provides flexible control for processing the shaft of a cylindrical gearbox for gears and bearings.

As a result of the study, the following conclusions can be drawn from the chapter:

- The developed algorithm for searching the FMS project based on the frame model allows you to accurately select its equipment, industrial robots, their layout scheme, and an automated control system from reliable sources in the global computer network, as well as suggest the final reliable layout and automation scheme.
- To ensure the reliable functioning of the FMS automatic control system and its production modules, an algorithm is proposed for searching for sensors and controlling the active elements of the FMS production module.
- To implement the proposed algorithms using frame models, the software was developed for an expert system of a frame type with fuzzy control of the shaft processing of a cylindrical gearbox for landing gear and bearings on a lathe in a flexible manufacturing module.

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