Eco-design of Mechatronic Systems

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Abstract. In conformity with the Kyoto Protocol, by the year 2020 the European Union undertook to reduce CO_2 emission by at least 20%. The main sources of this greenhouse gas are transport, combustion of fossil fuels for power generation, and some industrial processes [1]. The most effective ways to protect environment are based on pollution prevention and on searching and elimination of its causes. Application of this strategy to manufacturing processes led to formation of "eco-design" concept. This paper deals with life cycle assessment of mechatronic systems, in our case CNC machine tool. It contains analysis of energy and material consumption during raw material extraction for machine tool production and actual machine tool production. Afterwards, impacts of these life cycle phases on the environment were evaluated according to chosen impact categories.

1 Introduction

What is eco-design? It is a process of design and development of a product focused on minimizing of its negative impacts on environment during its whole life cycle. To term "eco-design" another term "LCA" (Life Cycle Assessment) is closely related. It is a methodology for evaluating of the potential environmental impacts connected with product life cycle. LCA is used in analytical phase of eco-design. During this phase determining of the product environmental profile and formulation of the requirements to the final product properties are realizing. It is possible to use this analysis for life cycle assessment of the products, services, and technologies.

The efforts to evaluate environment impacts of product life cycle on the environment date back already to the beginning of the 1970s years. Mainly, these studies were focused on waste management and packaging [2]. Since then, LCA was applied to many other products, for example current transformers [3], mobile telefon [4], shopping bag [5], beverage packing [6], fossil fuels and bioethanol [7], batteries [8], renewable energy technologies [9], comparison landfilling versus incineration of mixed municipal waste [10], silicon photovoltaic panels [11], etc.

Nowadays, the Energy-related Products Directive 2009/125/EC regulates the sphere of ecodesign. This Directive concerns all energy-related products including the mechatronic systems that are largely involved in deteriorating state of the environment. Worldwide industrial production consumes approximately ¼ of all

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electrical energy, because the mechatronic systems can be used in any industry where precise and reliable work is required. However, experience with LCA implementation is not so big in this sphere. For example, there are studies described in publication [12-14]. Therefore, in this paper LCA methodology will be applied right on representative of the mechatronic systems – CNC machine tool.

Before the article focuses on the application of LCA to the chosen machine tool, the mechatronic systems and LCA methodology will be generally described.

2 Mechatronic Systems

The mechatronic systems are a complex of electromechanical linkages and relations between a working mechanism and an electromechanical system. It is a system consisting of different energy carriers controlled by the numerical, mostly distributed systems. The mechatronic systems are used to develop and manufacture products of high quality and the highest technological level.

The typical mechatronic system consists of a motor, a transmission mechanism, an actuator (frequency converter), a control system (microcomputer), a switching and an overload devices [15].

Scheme of the mechatronic system is shown in Figure 1.

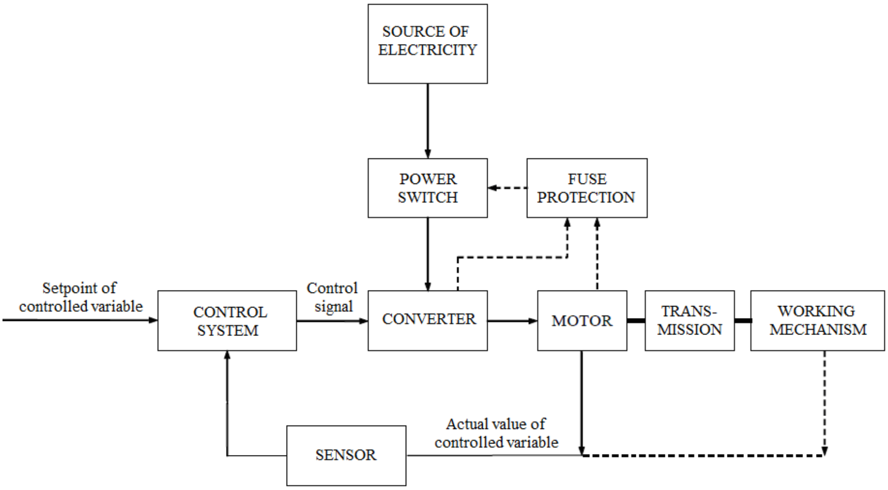

Fig. 1 Block diagram of the mechatronic system [15]

3 Life Cycle Assessment - LCA

As already mentioned in the introduction of this article, LCA is the methodology used for evaluating of potential product impact on the environment using the approach “from cradle to grave”. This approach takes into consideration all phases of life cycle – from the raw material extraction to the disposal of waste. LCA is the only tool that assesses the environmental impacts of the product during its whole life cycle. Therefore, it can be used to identify opportunities for improvements of the assessed product in all life cycle phases [15].

Currently there are two standards specifying LCA: ISO 14040 defines the principles and framework of LCA, ISO 14044 clarifies the requirements for LCA and guidelines for LCA performance. LCA methodology has a fixed structure and it is performed in accordance with international standards of ISO 14040 series. For effective processing of LCA studies, commercially available databases of processes as well as material and energy flows are used. LCA is defined for whole life cycle of the observed product. Then, the life cycle can be divided into five phases shown in Figure 2 [15].

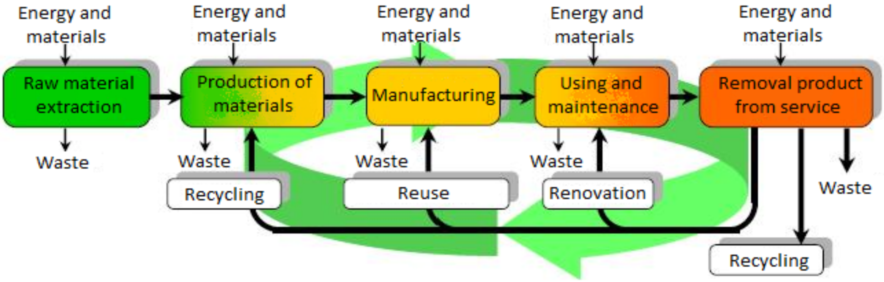

Fig. 2 Graphic representation of the product life cycle according to the ISO 14040 [15]

The study of the PE-International company and the LCA study have proved that phase of the machine using causes the biggest environmental burden, and energy consumption during machine operation has the biggest ecological impact [16]. For verification of this study, was suggested to use the principle described in publication [17]. It is possible to reduce energy consumption during machine operation already in the phases preceding its actual using. The paper deals with analysis and reducing of environmental burden during these phases.

For right LCA performance and determination of impacts on environment during whole life cycle, it is necessary to describe the assessed machine in detail.

4 Description of the Assessed Machine Tool

The LCA study was applied to the large CNC machine tool with horizontal headstock. This machine tool is used for to chip machining of material, also it can be used in such operations as milling, drilling, reaming and threading. It has modular design, which enables considerable variability of assembly. The machine tool consists of fixed sled, on which a stand moves in longitudinal direction. A console with laterally sliding horizontal headstock is placed vertically on the stand. Clamping space of workpiece is designed according to the customer requirements (clamping pates, rotary table, clamping squares, etc.) [15]. The block diagram of the assessed machine tool is shown in Figure 3.

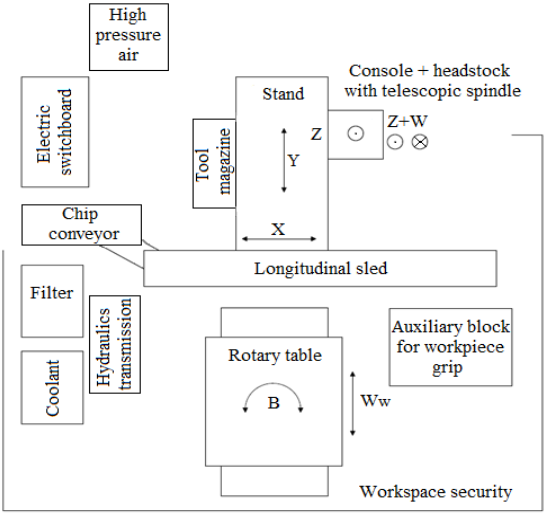

Fig. 3 The block diagram of assessed machine tool [15]

5 Realization of LCA Methodology on Assessed Machine Tool

Life cycle impact assessment of the machine tool was performed in the following order [15]:

1. During the first phase, aims and scope of study were determined. Also following impact category were chosen: global warming (kg CO_2 eq.), ozone layer depletion (kg CFC11 eq.), acidification (kg SO_2 eq.), photooxidants creation (kg C_2H_4 eq.), eutrophication (kg $PO_4$3-).
2. During the inventory analysis, data about ways of raw material obtaining, transportation, manufacturing, using of the assessed machine tool and its recykling were collected and processed. According to manufacturer's documentation, machine tool was laid out into structural units. Afterwards, material composition of each unit and the quantity of each material were described. From the above mentioned dividing for partial results for individual groups and total amount of consumed energy were determined. Results are presented in Figures 5 to 8.
3. In the third phase impact assessment of machine tool life cycle on environment was performed. To calculate the results of the inventory analysis LCA SW program Boustead Model was used. The results of the inventory analysis were converted into common units and the results were grouped within the impact categories. Afterwards, results of impact category indicator and partial results of ompact category indicator shown in Figures 9 to 13.

The results of performed study are presented in following charter.

6 Results of LCA Study

The results of performed study are shown graphically. Firstly, the results of inventory analysis are presented. They show total amount of consumed energy and energy consumed by partial machine tool components during the raw material extraction for their production and the actual production of these component [15].

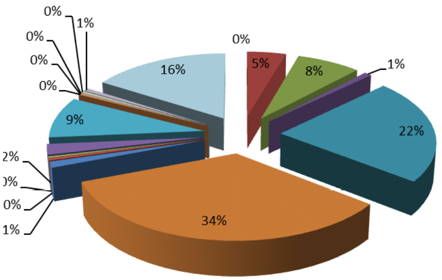

Fig. 4 Electric power consumption for particular machine tool components production

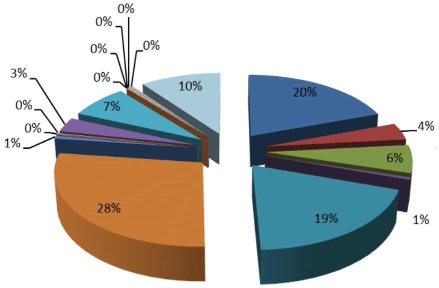

Fig. 5 Oil fuels consumption for particular machine tool components production

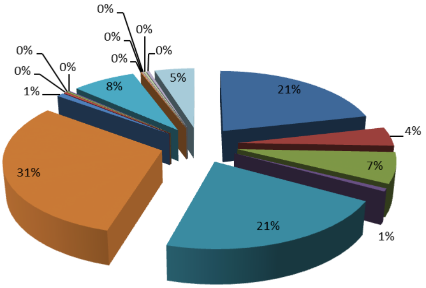

Fig. 6 Another fuels consumption for particular machine tool components production

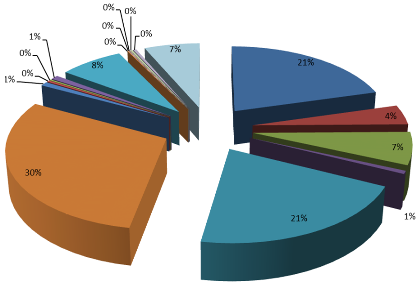

Fig. 7 Total energy consumption for particular machine tool components production

The grafs show that the following parts of machine tool consume the most of total energy: sled with revolving stand, sled and stand.

The results of the third LCA phase are shown in the form of partial graphs presenting environmental burden by particular machine tool components according to the chosen impact categories [15].

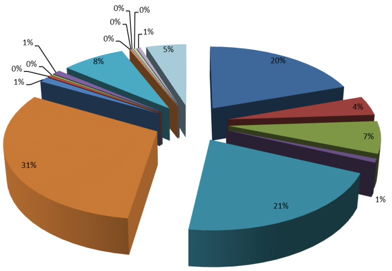

Fig. 8 Partial results of indicators for ozone layer depletion CO_2 eq.

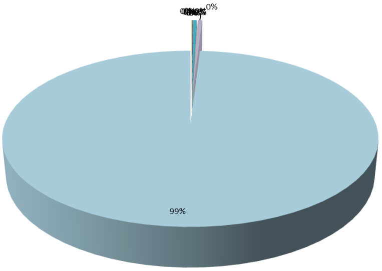

Fig. 9 Partial results of indicators for ozone layer depletion CFC-11 eq.

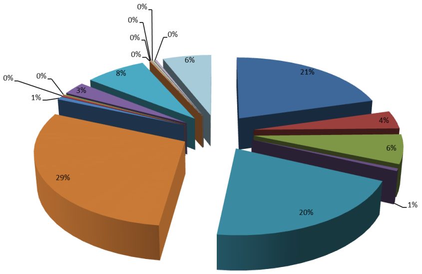

Fig. 10 Partial results of indicators for acidification SO_2 eq.

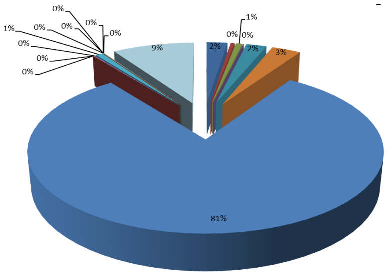

Fig. 11 Partial results of indicators for photooxidants creation C_2H_4 eq.

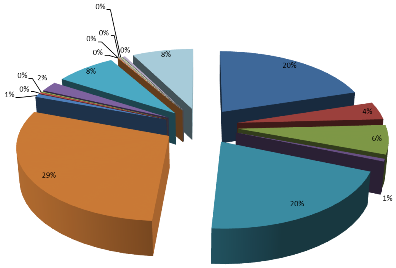

Fig. 12 Partial results of indicators for eutrophication PO_4^{3-} e

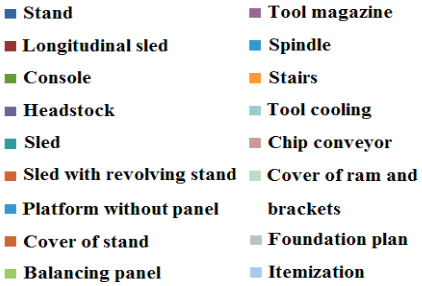

Fig. 13 Legend to Figures 5 to 13

According to the results of this phase, it is possible to make following conclusion about components the most burdening the environment in chosen impact categories: sled with revolving stand, sled and stand the most contribute to global warming and eutrophication; headstock the most contributes to ozone layer depletion; sled with revolving stand, sled, stand and headstock the most contribute to acidification; platform the most contributes to photooxidants creation.

Further, total amount of emissions in chosen impact categories produced during the raw material extraction and machine tool manufacture is presented (Table 1).

Table 1 Total amount of produced emissions [15]

Impact category	Amount	Unit
Global warming	3,81E+04	kg CO_2 eq.
Ozone layer depletion	1,85E-05	kg CFC11 eq.
Acidification	1,70E+02	kg SO_2 eq.
Photooxidants creation	3,73E+01	kg C_2H_4 eq.
Eutrophication	6,50E-05	kg $PO_4$3-

7 Conclusions

This article summarizes the results of LCA method application on mechatronics systems represented by machine tool. The main contribution of this paper is analysis of energy and material consumption of assessed CNC machine tool during raw material extraction for its production and actual machine tool production. Furthermore, the impact evaluation of the mentioned life cycle phases of machine tool on the environment.

As already mentioned, the phase of the machine tool using has the biggest impact on the environment. It is possible to influence this phase and following phases already in the preceding phases. The results of the performed study can be used to reduce the environmental burden and energy performance of machine tools. All of this can be realized by way of choosing of more environment-friendly materials, ways of their extraction, transportation, processing technologies, exchange of machine components for the more energy and material efficient components, etc.

Nevertheless, design of energy-efficient and safe machine requires comprehensive assessment of its whole life cycle, because the efforts to correct ecological impacts although lead to improvement in one area, but often lead to environmental deterioration elsewhere. Then it is necessary to consider if it is appropriate to take such corrective action at all.

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