TOOLS FOR VISUALIZATION OF ENERGY FLOWS IN THE CONSTRUCTION OF MACHINE-TOOLS

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The article deals with the development of tools supporting a higher degree of visualization in order to assess the workload of electrical appliances installed in machine-tools. A higher degree of visualization means to forward the interpretation of the results from commonly used tables, graphs, and also 2D visualization, to 3D visualization. This enables us a considerably easier orientation in the virtual phase of the design and the control of not only the energy consumption of the machine-tools, but also of their structural nodes. The first part of the article deals with the possibilities and application of 3D visualization including the work with the required input data. There is a detailed description of how to construct the necessary data to create a 3D model, if these data are not available. The second part is concerned with the application created for simulation of energy flows in the machine-tool in dependency on time. There are described some of the obstacles that must be solved and also the benefits of the proposed solutions for the user. Finally, the present article briefly describes possible future developments of the software concerned. The tool developed for visualization was applied to the machine FUEQ 125 Efektiv company TOS Kurim in cooperation with the Czech Technical University in Prague, Faculty of Mechanical Engineering, VCSVTT – Research Centre for Manufacturing Engineering and Technology.

Keywords
Ecodesign, machine-tools, visualization, energy flows, simulation

1. Introduction

The essence of the following article is to present the application created in order to study the impacts of both conceptual and constructional changes of the equipment (machine tools), collectively called Ecodesign.

According to the publication of the Ministry of Environment (MZP), Ecodesign can be defined as a systematic design process of product development, which in addition to traditional characteristics such as functionality, economy, safety, ergonomics, technical feasibility, aesthetics, etc., places a great emphasis on achieving a minimal negative environmental impact of the product in terms of its life cycle [Remtova 2003].

This description is very general; therefore, several analyses have been used for evaluation. The method of "Lowest Life Cycle Cost" (LLCC), allows determining a total cost of ownership and operation of a particular product. LLCC is used to set a particular target minimum of these costs, where the space between this minimum and the current state enables us to maintain a space for innovation (competition).

To ensure the necessary innovation, the product is compared with the "Best Available Technologies" (BAT); in simple terms, using the best available technologies. These are technologies expected to be introduced into a standard product within a short time horizon.

A comparison with the best non-available technologies (BNAT), i.e. with a top of the current state of the art in research and product development, indicates a possible market development in a longer time horizon.

All of these methods are only used to determine the potential for improvement and the direction in which this improvement could occur. After particular interventions and changes of technical nature, it is of course necessary to analyse the benefits in particular terms.

The measured data have to be evaluated; for clear illustration of dependences of the individual variables, it is convenient to use a graphical evaluation. Therefore the essence of the proposal was to create an interface for visualization of energy flows measured on a machine tool. Other requirements on the application were to monitor the consumption of the given variable for the selected appliances in time and on real points of the machine.

2. Current state

To determine the specific benefits for the product – in this case the machine tool – measuring of the energy flows and evaluation are used; the output being usually the data arranged in tables, graphs, or Sankey diagrams. Because of the need to display all the data in a single view, using Sankey diagrams for visualization has been selected. Predicative values of the above tools can be further extended to the applications based on 3D visualization. A further degree of reality increase is the use of VR tool (Virtual Reality). This article will be dedicated to Ecodesign issues and to a higher degree of visualization to assess the energy demands of machine tools. Tools for VR visualization have already been presented (Fig.1)

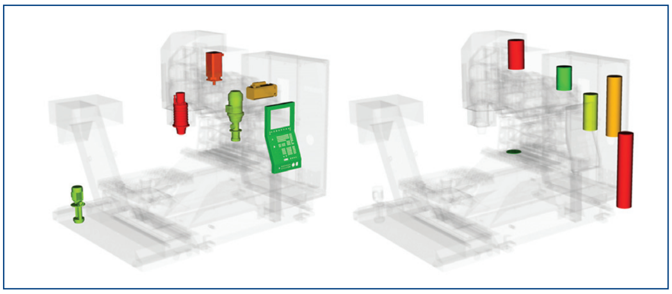


Figure 1. *Possibilities of energy flow visualization in 3D [Neugebauer 2011]*

Our goal is to create a solution for visualisation of energy flows and to create a simple user interface. The tools to realise this goal are analysed in detail in the following text.

2.1 Sankey diagram

The basic tool for visualization of energy flows is a Sankey diagram in 2D (Fig. 2). They are not visualized together with machine so it could by sometimes hard to understand them. We could also make them as a layer on picture of the machine but3D modelling is increasingly used for design so the most of machine producers have their machine as 3D data. Making visualisation in 3D enables to obtain a space for extension allowing an increase in the overall visual impression; e.g. by a complex kinematic simulation along with the simulation of energy flows.

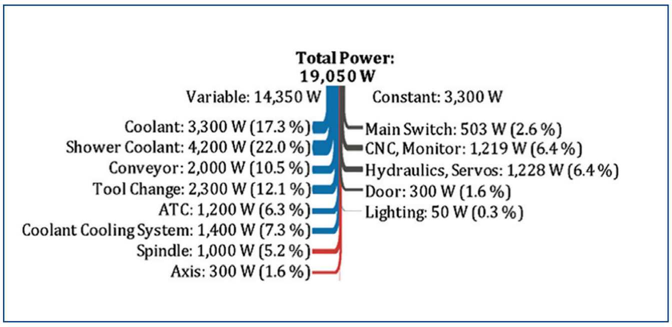


Figure 2. *Example of simple Sankey diagram in 2D [Behrendt 2012]*

Sankey diagram appearance is well defined in 2D but we have to decide how to make them in 3D using mostly primitive 3D shapes. Transfer from 2D to 3D has been implemented in a similar way to that described in the work of authors [Neugebauer 2011], i.e. by using primitive bodies and a change of their specific dimensions relatively to flow.

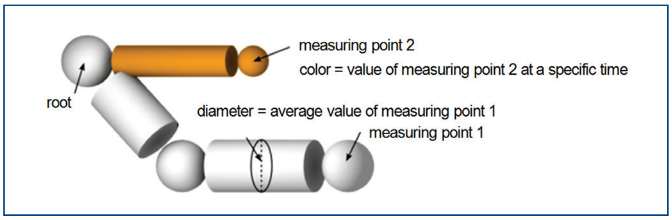


Figure 3. *Sankey diagrams using primitive bodies [Neugebauer 2011]*

3. Ecodesign application in machine tools

For application development and testing was used data measured on floor type machining centre FU EFEKTIV (Fig. 4). Machine FUE(Q) 125 EFEKTIV is installed in TOS Kuřim.

Figure 4. *Installed machine FUE(Q) 125 EFEKTIV in TOS Kuřim*

3.1.. Application for simulation of energy flows

There is indeed a great deal of approaches of how to realize this task; these vary both in term of complexity and demands on programming skills and, on the other hand, in terms of possibilities and limitations. The application must allow a complete support for product development with regard to energy efficiency [Rünger 2011].

The most demanding approach is a complete programming; e.g. using OpenGL. On the other hand, such an approach gives a great freedom to developers, and then also a considerable comfort to users. What makes this task difficult is not to display the diagrams consisting of 3D primitive bodies (cylinder, sphere). In fact these diagrams are shown above the design data and to display them, especially when it is a production machine with thousands of components, is not an easy task. Actually, the components are usually made up of groups of NURBS surfaces.

The approach, which is thus directly offered, is visualization in 3D CAD application. First, CAD is often used to design the equipment and therefore it makes sense to perform the analysis directly in the design application on the machine data. The easiest way is then a manual completion of modelling of 3D Sankey diagrams directly in the design data. Visualization of time changes of flows, i.e. a change in diameter of 3D cylinder, can be realized using a parameter that controls the diameter and whose value is loaded from the table of variants. Similar approaches are offered by nearly all of the leading 3D CAD applications. The greatest disadvantage is then the manual work itself in the form of modelling and connecting the parameters to the data source. Preparation of visualization would be very demanding and difficult to cover the changes in the variants and a product series.

As a proper solution, the use of CAD applications with the programmed Add-in was selected. As a CAD application, Autodesk Inventor 2013 was selected not only because the faculty owns a licence, but mainly because of the very well-described developmental interface (co-called SDK) for programming of external modules. For these external modules (in English called Add-in), there is an offer platform, similarly to that known from mobile phones. This allows Add-in to be offered for free to millions of users of this application all over the world and thus to get a quality feedback, which is often needed for development.

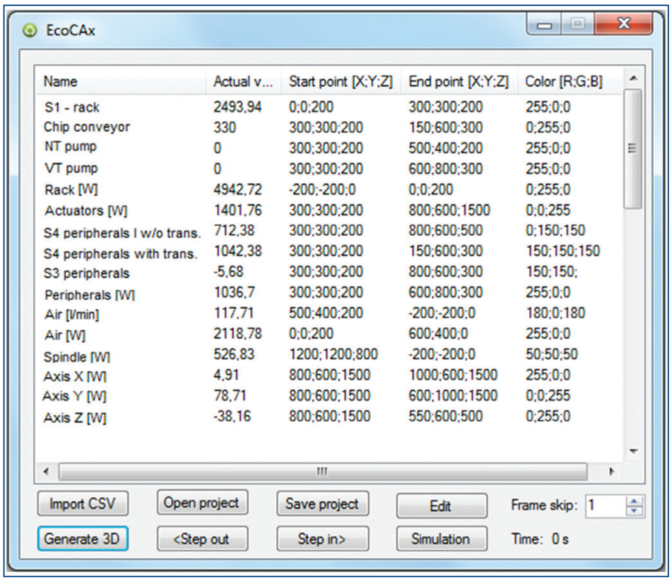


Figure 5. *Work window of EcoCAx application*

3.2 Machine analysis and degree of visualization

Inputs into the proposed application can be machine tool models that would provide the highest degree of visualization (Fig.6); a lower degree is the assembly of simplified machine tool model (Fig. 5) or a photo of real machine (Fig. 4). Another input into the system are the data obtained from measurements supplemented with the placement of individual or grouped measured electrical appliances (according to the layout chart of electrical appliances). Based on these charts, a network of monitored energy flows will be created on the machine tool.

Workflow used throughout the simulation development does not significantly differ for the individual above-mentioned variants in terms of their complexity. Provided that detailed 3D design data are available, it is in most cases suitable to use them.

If these data were not provided by the equipment manufacturer, it is necessary to consider some of the alternative options, especially with regard to time demands and quality requirements. The subject of this article is to work with 3D data; therefore two variants of their quality are now discussed.

3.1.1 Simplified model of machine tool

In the machine, energy nodes are selected where it is necessary to simulate the flows. These nodes are transferred to the primitive bodies using a substitution with bounding box. In the next step, the parts unattractive in energy terms are created in the same way; however these parts are important to understand the machine topology.

The principle of the bounding box is also used in the case when the quality 3D data have already been provided but it is necessary to protect the intellectual property of the manufacturer. The second case is the use of highly detailed data when the data loading itself

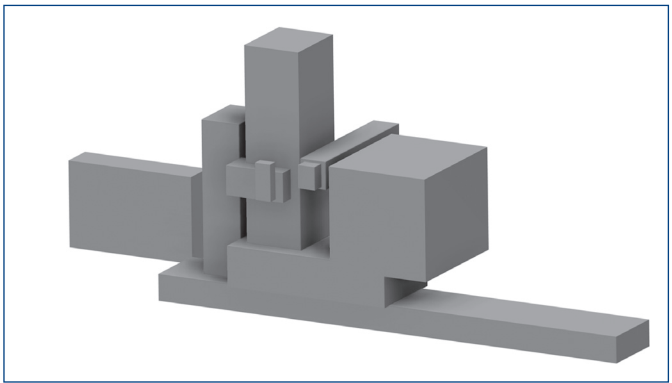


***Figure 6.** Simplified model of machine FUE(Q) 125 EFEKTIVE*

places high demands on computations and can slow down the simulation itself.

3.1.2 Detailed model of machine

To implement higher degrees of visualizations, quality 3D data are required. Very often, these data are not available; it was also the case of the machine used for visualization. In connection with this, one of the workflows of 3D data creation will be presented in this article.

To create this model, two drawing views (front view and side view) were used in the CAD and 3D CAD Autodesk Inventor with a special module.

To obtain 2D drawing views, a catalogue in PDF format can be used. Assuming that a good catalogue is available, the drawing data in this catalogue are in vector format. To extract the data from PDF, software open source vector graphics editor Inkscape was used; this allows loading PDF files in adjustable quality and exporting them to CAD format DXF. It can be loaded into 2Dto3D Add-in of Autodesk Inventor software. This allows aligning of p picture.

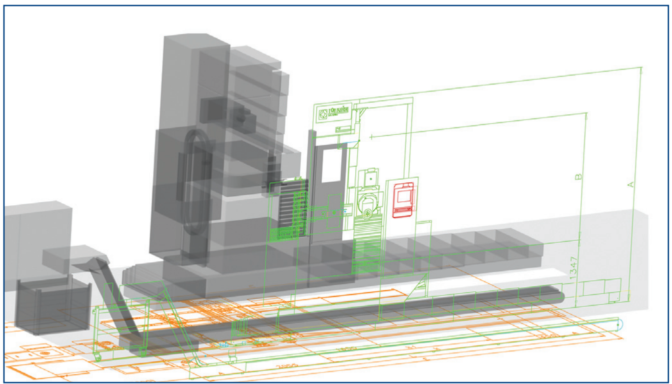


***Figure 7.** Creation of 3D data from 2D drawings extracted from the catalogue*

3.2 Workflow in application

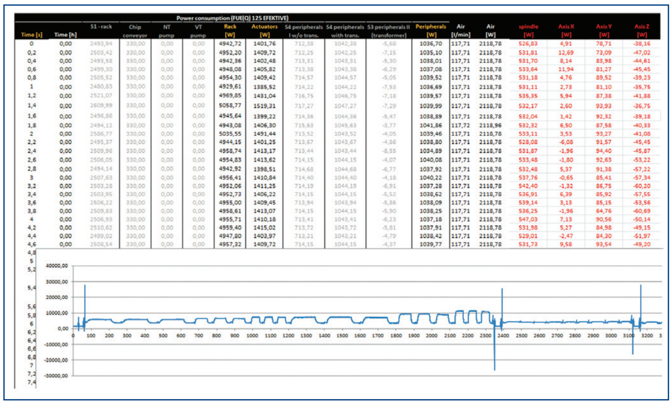
Visualization workflow is based on the opening of design data in the Autodesk Inventor application. These data can be either native (created directly in this application) or imported from various other formats of CAD applications or converted using the exchange format (e.g. STEP).

3.2.1 Measured data input

Application must visualize the data that represent the output of measurement – the values in text format separated by commas. Application must visualize measured data so as first step we have to import data. Energetic map of machine includes data measured during making specific tasks (Fig.). One of them has to be chosen and transferred into the CSV format, where the individual columns represent the measurement points and these are assigned to the start and end of the branches of Sankey diagram. This can be performed either by specification of spatial coordinates in the format [X, Y, Z] in millimetres or by direct selection of the point on 3D geometry using the mouse cursor.

First row of CSV is automatically used as name for the each measured point.

This solution enables to visualize Sankey diagrams on various types of machines.



Power consumption (FUE(Q) 125 EFEKTIVE)

Time [s]	Time [h]	S1 - rack	Chip conveyor	NT pump	VT pump	Rack [W]	Actuators [W]	S4 peripherals I w/o trans.	S4 peripherals with trans.
0	0,00	2493,94	330,00	0,00	0,00	4942,72	1401,76	712,38	1042,38
0,2	0,00	2503,42	330,00	0,00	0,00	4952,20	1409,72	712,25	1042,25
0,4	0,00	2493,58	330,00	0,00	0,00	4942,36	1402,48	713,31	1043,31
0,6	0,00	2499,30	330,00	0,00	0,00	4948,08	1405,82	713,38	1043,38
0,8	0,00	2505,52	330,00	0,00	0,00	4954,30	1409,42	714,57	1044,57
1	0,00	2480,83	330,00	0,00	0,00	4929,61	1385,52	714,22	1044,22
1,2	0,00	2521,07	330,00	0,00	0,00	4969,85	1431,04	716,75	1046,75
1,4	0,00	2609,99	330,00	0,00	0,00	5058,77	1519,31	717,27	1047,27
1,6	0,00	2496,86	330,00	0,00	0,00	4945,64	1399,22	714,36	1044,36
1,8	0,00	2494,12	330,00	0,00	0,00	4943,08	1406,30	715,63	1045,63
2	0,00	2586,77	330,00	0,00	0,00	5035,55	1491,44	713,52	1043,52
2,2	0,00	2495,37	330,00	0,00	0,00	4944,15	1401,25	713,67	1043,67
2,4	0,00	2509,96	330,00	0,00	0,00	4958,74	1413,17	713,44	1043,44
2,6	0,00	2506,05	330,00	0,00	0,00	4954,83	1413,62	714,15	1044,15
2,8	0,00	2494,14	330,00	0,00	0,00	4942,92	1398,51	714,68	1044,68
3	0,00	2507,63	330,00	0,00	0,00	4956,41	1410,84	714,40	1044,40
3,2	0,00	2503,28	330,00	0,00	0,00	4952,06	1411,25	714,19	1044,19
3,4	0,00	2503,95	330,00	0,00	0,00	4952,73	1406,22	714,15	1044,15
3,6	0,00	2506,22	330,00	0,00	0,00	4955,00	1409,45	713,94	1043,94
3,8	0,00	2509,83	330,00	0,00	0,00	4958,61	1413,07	714,15	1044,15
4	0,00	2506,93	330,00	0,00	0,00	4955,71	1410,18	713,41	1043,41
4,2	0,00	2510,62	330,00	0,00	0,00	4959,40	1415,02	713,72	1043,72
4,4	0,00	2499,02	330,00	0,00	0,00	4947,80	1403,97	713,21	1043,21
4,6	0,00	2508,54	330,00	0,00	0,00	4957,32	1409,72	714,15	1044,15

Time [s]	S3 peripherals II (transformer)	Peripherals [W]	Air [l/min]	Air [W]	spindle [W]	Axis X [W]	Axis Y [W]	Asis Z [W]
0	-5,68	1036,70	117,71	2118,78	526,83	4,91	78,71	-38,16
0,2	-7,15	1035,10	117,71	2118,78	531,81	12,69	73,09	-47,02
0,4	-5,30	1038,01	117,71	2118,78	531,70	8,14	83,98	-44,61
0,6	-6,29	1037,08	117,71	2118,78	533,64	11,94	81,27	-45,45
0,8	-5,05	1039,52	117,71	2118,78	531,18	4,76	89,52	-39,23
1	-7,53	1036,69	117,71	2118,78	531,11	2,73	81,10	-35,75
1,2	-7,18	1039,57	117,71	2118,78	535,35	5,94	87,38	-41,88
1,4	-7,29	1039,99	117,71	2118,78	532,17	2,60	93,93	-36,75
1,6	-5,47	1038,89	117,71	2118,78	532,04	1,42	92,32	-39,18
1,8	-3,77	1041,86	117,72	2118,96	532,32	6,50	87,58	-40,33
2	-4,05	1039,46	117,71	2118,78	533,11	3,53	93,27	-41,08
2,2	-4,86	1038,80	117,71	2118,78	528,08	-6,08	91,57	-45,45
2,4	-8,55	1034,89	117,71	2118,78	531,87	-1,96	94,40	-45,87
2,6	-4,07	1040,08	117,71	2118,78	533,48	-1,80	92,63	-53,22
2,8	-6,77	1037,92	117,71	2118,78	532,48	5,37	91,38	-57,22
3	-4,18	1040,22	117,71	2118,78	537,76	-0,65	85,41	-57,34
3,2	-6,91	1037,28	117,71	2118,78	542,40	-1,32	86,75	-60,20
3,4	-5,52	1038,62	117,71	2118,78	536,91	6,39	85,92	-57,55
3,6	-5,86	1038,09	117,71	2118,78	539,14	3,13	85,15	-53,56
3,8	-5,90	1038,25	117,71	2118,78	536,25	-1,96	64,76	-60,69
4	-6,23	1037,18	117,71	2118,78	547,03	7,13	90,56	-50,14
4,2	-5,81	1037,91	117,71	2118,78	531,98	5,27	84,98	-49,15
4,4	-4,79	1038,42	117,71	2118,78	529,01	-2,47	84,30	-51,97
4,6	-4,37	1039,77	117,71	2118,78	531,73	9,58	93,54	-49,20

***Figure 8.** Example of table with measured data*

3.2.2 Time simulation

After opening appropriate 3D data and setting up whole table 3D Sankey diagram could be generated.It will automatically render the diagrams in time t = 0 and simulation can be started.

As already stated,.

Rows represent individual measurement periods with regular sampling, while columns represent the objects monitored in terms of energy flows. The application operates on the principle of frame, i.e. the step which is represented by one row in the table. The provided data were measured in very small intervals; this in practice has proved to be problematic. In fact, there are limitations due to power capabilities of the system, i.e. by the maximum FPS frequency, and further it was found out that the data slightly oscillate and thus the displayed course was not sufficiently representative. The application was therefore extended using a frame skip, i.e. the function that allows setting the minimum displayed time delays. This enables the application to optimally supply the graphical information on peaks and other extreme points of the time course; these regions can then be investigated in detail in the regime of reduced speed.

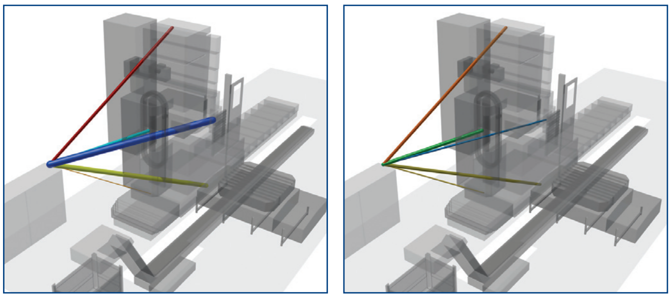


***Figure 9.** Visualization of energy flows according to real measured data*

3.3 Practical use and future development of application

Thanks to this application, it is mainly possible to create 3D models of Sankey diagrams very quickly and to create their animations for various measurements and also for machine variants. Visualization of Sankey diagrams themselves is used to obtain clear concepts and enables the users to display in one window the energy flows in the device containing theoretically an unlimited number of components and to simulate this characteristic in time. Compared with visualization of dependencies in several diagrams, mainly due to the adjustable distinguishableness at any point of the graph, it allows an easy comparison of several variants.

The planned further development is to expand the application possibilities. One of the planned functions is a connection between the simulation of machine motion and energy flows. This allows displaying the course of values in the highest visual interpretation.

Furthermore, e.g. the connection was tested between the ECOCAX application with PLC and the simulation of higher kinematic structures. E.g. an independently tested example with parallel kinematics allows simulating the work of individual actuators based on the PLC output. The system would then allow the users to monitor Ecodesign throughout the performance of motions determined by PLC and to simultaneously solve collisions that may occur. Basically, in this way, it is possible to monitor how the control system performs in certain situations and how this course affects the efficiency of the machine.

Conclusions

In the area of simulations of physical actions, both at high scientific level and also at general level, mile shifts occur. This system is designed to provide an integrated support to developers who encounter mechatronics. At the same time, the aim is not to create a perfect simulation environment, but rather to focus on mediation of outcomes or post-processing directly into the CAD application, in this case Autodesk Inventor. Due to the feedback, the simulation of motion can be shifted to a higher level. This system would also allow determining, in terms of at least a one-sided view, the expected difference between the two processes with the same result but with a different course; in this case considering the Ecodesign evaluation. It adds the possibility to select from among several variants, i.e. it is a visual decision-making platform for Ecodesign.

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