An automation of design and modelling tasks in NX Siemens environment with original software – cost module

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Abstract. The design-constructional process is a creation activity which strives to fulfil, as well as it possible at the certain moment of time, all demands and needs formulated by a user taking into account social, technical and technological advances. Engineer knowledge and skills and their inborn abilities have the greatest influence on the final product quality and cost. They have also deciding influence on product technical and economic value. Taking into account above it seems to be advisable to make software tools that support an engineer in the process of manufacturing cost estimation. The Cost module is built with analytical procedures which are used for relative manufacturing cost estimation. As in the case of the Generator module the Cost module was written in object programming language C# in Visual Studio environment. During the research the following eight factors, that have the greatest influence on overall manufacturing cost, were distinguished and defined: (i) a gear wheel teeth type it is straight or helicoidal, (ii) a gear wheel design shape A, B with or without wheel hub, (iii) a gear tooth module, (iv) teeth number, (v) gear rim width, (vi) gear wheel material, (vii) heat treatment or thermochemical treatment, (viii) accuracy class. Knowledge of parameters (i) to (v) is indispensable for proper modelling of 3D gear wheels models in CAD system environment. These parameters are also processed in the Cost module. The last three parameters it is (vi) to (viii) are exclusively used in the Cost module. The estimation of manufacturing relative cost is based on indexes calculated for each particular parameter. Estimated in this way the manufacturing relative cost gives an overview of design parameters influence on the final gear wheel manufacturing cost. This relative manufacturing cost takes values from 0.00 to 1.00 range. The bigger index value the higher relative manufacturing cost is. Verification whether the proposed algorithm of relative manufacturing costs estimation has been designed properly was made by comparison of the achieved from the algorithm results with those obtained from industry. This verification has indicated that in most cases both group of results are similar. Taking into account above it is possible to draw a conclusion that the Cost module might play significant role in design constructional process by adding an engineer at the selection stage of alternative gear wheels design. It should be remembered that real manufacturing cost can differ significantly according to available in a factory manufacturing techniques and stock of machine tools.

1. Introduction
It is assumed that almost 80% of product development process cost arises at the design stage [1, 2]. Therefore there is still a need for an appropriate methods and software tools which could help
designers at proper design making [3, 4]. In the paper a method and software tool for manufacturing cost estimation is presented. In this method of gear wheels the relative manufacturing cost evaluation the following factors with the greatest influence on manufacturing cost were distinguished: (i) a gear wheel teeth type, (ii) a gear wheel design shape A, B with or without wheel hub, (iii) a gear tooth module, (iv) teeth number, (v) gear rim width, (vi) gear wheel material, (vii) heat treatment or thermochemical treatment, (viii) accuracy class. For each particular factor the corresponding relative manufacturing cost coefficient can be ascribed (see: the table 1):

$k_{rz}$ – relative manufacturing cost coefficient on account of a gear wheel teeth type:

$$k_{rz} = \frac{wrz}{wrz_{max}}$$  \hspace{1cm} (1)

$k_f$ – relative manufacturing cost coefficient on account of a gear wheel design shape:

$$k_f = \frac{wf}{wf_{max}}$$  \hspace{1cm} (2)

$k_m$ – relative manufacturing cost coefficient on account of a gear tooth module:

$$k_m = \frac{wm}{wm_{max}}$$  \hspace{1cm} (3)

$k_z$ – relative manufacturing cost coefficient on account of teeth number:

$$k_z = \frac{wz}{wz_{max}}$$  \hspace{1cm} (4)

$k_w$ – relative manufacturing cost coefficient on account of gear rim width:

$$k_w = \frac{ww}{ww_{max}}$$  \hspace{1cm} (5)

$k_f$ – relative manufacturing cost coefficient on account of gear wheel material:

$$k_f = \frac{wf}{wf_{max}}$$  \hspace{1cm} (6)

$k_o$ – relative manufacturing cost coefficient on account of heat treatment or thermochemical treatment:

$$k_o = \frac{wo}{wo_{max}}$$  \hspace{1cm} (7)

$k_k$ – relative manufacturing cost coefficient on account of accuracy class:

$$k_k = \frac{wk}{wk_{max}}$$  \hspace{1cm} (8)
Each relative manufacturing cost coefficient variant \( w_x \) can take value from the range of \( \{0, \ldots, n\} \) where \( n \) is an appropriate natural number (see: the table 1). There is a relation between a relative manufacturing cost value and manufacturing cost, greater relative manufacturing cost value means greater real manufacturing cost.

Relative manufacturing cost coefficients on account of a gear wheel teeth type and gear wheel design shape can take values from the range of \( \{0,1\} \). The maximum values for coefficient variants \( w_x \) were denoted in red (table 1).

**Table 1.** Gear wheels design parameters with corresponding values of coefficients variants \( w_x \).

| Teeth number | \( w_z \) | Gear rim width \( w_w \) | Gear wheel material \( w_f \) | Heat treatment or thermochemical treatment \( w_o \) | Accuracy class \( w_k \) |
|--------------|----------|-----------------|-----------------|--------------------------|--------|
| 17-26        | 1        | 1-10            | C35             | Without                  | 5      |
| 27-36        | 2        | 11-20           | C45             | 1                        | 6      |
| 37-46        | 3        | 21-30           | C55             | Single hardening         | 7      |
| 47-56        | 4        | 31-40           | C10             | 2                        | 8      |
| 57-66        | 5        | 41-50           | C15             | Double hardening         | 9      |
| 67-76        | 6        | 51-60           | 15Cr2           | 3                        | 10     |
| 77-86        | 7        | 61-70           | 20Cr4           | Carburizing              | 11     |
| 87-96        | 8        | 71-80           | 34CrMo4         | 4                        | 12     |
| 97-106       | 9        | 81-90           | 37MnSi5         | 5                        |        |
| 107-116      | 10       | 91-100          | 14HG            | 0.05                     | 1      |
| 117-126      | 11       | 101-110         | 20MnCr5         | 0.14                     | 10     |
| 127-136      | 12       | 111-120         | 18CrMo4         | 0.45                     | 20     |
| 137-146      | 13       | 121-130         | 13CrMo4-5       | 1.375                    | 30     |
| 147-156      | 14       | 131-140         | 18CrNi8         | 2                        | 2.5    |
| 157-166      | 15       | 141-150         | 45HN            | 6                        | 4.5    |
| 167-176      | 16       | 36CrNiMo4       | 7               | 14                       | 50     |
| 177-186      | 17       | 34CrNiMo6       | 8               | 1                        | 25     |
| 187-200      | 18       | 30H2N2M         | 2               | 2                        | 90     |

The overall relative manufacturing cost for a given gear wheel can be calculated according to the following formula (value of each \( k_{x_{\text{max}}} = 1 \)):

\[
k_c = \frac{k_{r_z} + k_f + k_m + k_z + k_w + k_t + k_o + k_k}{k_{r_z_{\text{max}}} + k_f_{\text{max}} + k_m_{\text{max}} + k_z_{\text{max}} + k_w_{\text{max}} + k_t_{\text{max}} + k_o_{\text{max}} + k_k_{\text{max}}}
\]

**2. Illustrative example**

The presented example shows relative manufacturing calculations for the three gear wheels parts produced by an enterprise. The design parameters of the subjected parts in the table 2 are shown.
The detailed calculations for particular relative manufacturing cost coefficients in the table 3 are presented.

Table 3. Results of relative manufacturing cost coefficient calculations.

| Relative manufacturing cost coefficient | Gear wheel I | Gear wheel II | Gear wheel III |
|----------------------------------------|-------------|--------------|---------------|
| $k_{rz} = \frac{w_{rz}}{w_{rz_{\text{max}}}}$ | $k_{r_1} = \frac{1}{2} = 0.5$ | $k_{r_2} = \frac{1}{2} = 0.5$ | $k_{r_3} = \frac{2}{2} = 1$ |
| $k_{f} = \frac{w_{f}}{w_{f_{\text{max}}}}$ | $k_{f_1} = \frac{2}{2} = 1$ | $k_{f_2} = \frac{1}{2} = 0.5$ | $k_{f_3} = \frac{2}{2} = 1$ |
| $k_{m} = \frac{w_{m}}{w_{m_{\text{max}}}}$ | $k_{m} = \frac{27}{66} = 0.41$ | $k_{m_2} = \frac{33}{66} = 0.5$ | $k_{m_3} = \frac{45}{66} = 0.68$ |
| $k_{z} = \frac{w_{z}}{w_{z_{\text{max}}}}$ | $k_{z} = \frac{2}{18} = 0.11$ | $k_{z_2} = \frac{1}{18} = 0.06$ | $k_{z_3} = \frac{3}{18} = 0.17$ |
| $k_{w} = \frac{w_{w}}{w_{w_{\text{max}}}}$ | $k_{w_1} = \frac{3}{15} = 0.2$ | $k_{w_2} = \frac{2}{15} = 0.13$ | $k_{w_3} = \frac{8}{15} = 0.53$ |
| $k_{t} = \frac{w_{t}}{w_{t_{\text{max}}}}$ | $k_{t} = \frac{5}{8} = 0.63$ | $k_{t_2} = \frac{1}{8} = 0.13$ | $k_{t_3} = \frac{1}{1} = 1$ |
| $k_{o} = \frac{w_{o}}{w_{o_{\text{max}}}}$ | $k_{o} = \frac{4}{4} = 1$ | $k_{o_2} = \frac{2}{4} = 0.5$ | $k_{o_3} = \frac{1}{4} = 0.25$ |
| $k_{k} = \frac{w_{k}}{w_{k_{\text{max}}}}$ | $k_{k} = \frac{6}{8} = 0.75$ | $k_{k_2} = \frac{8}{8} = 1$ | $k_{k_3} = \frac{3}{8} = 0.38$ |

Finally the value of overall relative manufacturing cost for particular wheels is as follows:

- for the gear wheel I

$$k_{c_1} = \frac{0.5 + 1 + 0.41 + 0.11 + 0.2 + 0.63 + 1 + 0.75}{8} = \frac{4.6}{8} = 0.58$$

- for the gear wheel II

$$k_{c_2} = \frac{0.5 + 0.5 + 0.5 + 0.06 + 0.13 + 0.13 + 0.5 + 1}{8} = \frac{3.19}{8} = 0.40$$
- for the gear wheel III

\[
k_{c3} = \frac{1+1+0.68+0.17+0.53+1+0.25+0.38}{8} = \frac{5.01}{8} = 0.63
\]  

(12)

It should be remembered that the proposed method of relative manufacturing cost calculation gives a general view on manufacturing cost. It arises from the fact that the particular relative manufacturing cost coefficients were not defined with the high accuracy taking into account that they were defined in a subjective manner. Application of this method in an enterprise needs additional actions to be done. It could be necessary to change relative manufacturing cost values and in some case to introduce a system of coefficient weights for design parameters.

3. The cost module

The cost module is a part of the original software designed to support an engineer during their work with gear wheels design modelling and fast relative manufacturing cost calculation (figure 1). Worked out software, developed in Microsoft Visual Studio 2012, works only in Siemens NX environment. The original software is composed of the two main modules; it is the generator module and cost module. Generator module is used for gear wheels geometric parameters calculations and 3D modelling.

Figure 1. The original program structure.

The cost module is composed of computational procedures built on general idea of relative manufacturing cost calculation presented in this paper. The cost module gives a designer a general view of the impact of particular gear wheels design parameters on the final product economic efficiency so it supports the designer making their work easier. During conducted research the tests were carried out to verify the correctness of cost module. The research program included relative manufacturing cost calculations for 12 different gear wheel designs. The calculated relative costs were next compared with real manufacturing cost. Information about real manufacturing costs was achieved from the two independent producers. In figure 2 the comparison between calculated relative manufacturing costs and real manufacturing costs is presented. The analysis of the figure 2 shows that the difference between real manufacturing costs in case of the same gear wheel design for both producers is small. The differences between real manufacturing costs for different gear wheels designs differs a lot but differences in calculated relative cost not. The small difference in relative manufacturing cost for particular gear wheels designs makes the evaluation of the influence of the designer decisions on design economic effectiveness difficult. In order to correct this phenomenon it was necessary to introduce weights system for relative manufacturing cost coefficients. The figure 3 shows the distinct improvement in relative manufacturing cost calculation. The overall relative manufacturing costs coefficients are almost at the same level as real manufacturing cost.
It is difficult to match relative and real manufacturing cost perfectly because during the research it was impossible to achieve information about producer’ margins, they are probably different for each producer. Industrial application of the cost module needs the stage of weights system to be done. In such a case relative manufacturing cost results could be very useful for a designer helping them to choose correct design decisions.

**Figure 2.** The comparison between real manufacturing cost and calculated relative manufacturing cost.

**Figure 3.** The comparison between real manufacturing cost and calculated relative manufacturing cost with weight system.

### 4. Conclusions

In contemporary industry cost estimation is considered as a strategic tool which can be applied to help decision making. It assumed that up to 80 percent of the product cost is determined by decisions taken by designers at the design-constructional stage. Therefore it is important to estimate manufacturing costs as early and as precisely as it is possible. Presented in the paper method and software tool is an answer to this problem.

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