USE OF THE UNIGRAPHICS/NX PROGRAM FOR STATOR COIL DESIGN

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The article deals with the description and creation of a parametric model of the generator's stator winding coil using the Unigraphics/NX program. It contains a detailed procedure for designing a parametric model, including the creation of basic planes, link to another application, and entering parametric environment.

Key words: *Unigraphics/NX, generator, stator coil, winding, construction, parametric model*

1. Introduction

Unigraphics/NX is a comprehensive **CAD/CAM/CAE** system to support a wide array of activities related to design and manufacture, including initial conceptual design, calculations, simulations and analyses, modeling both individual parts and whole assemblies, creation of drawings, programming NC machine tools and measuring machines, simulation of the machining process, quality control, data and project administration with their integration into the company information system.

NX is a modern modular system featuring a full association of all cooperating modules that is built over a uniform object-oriented graphic database. This enables a team of engi-

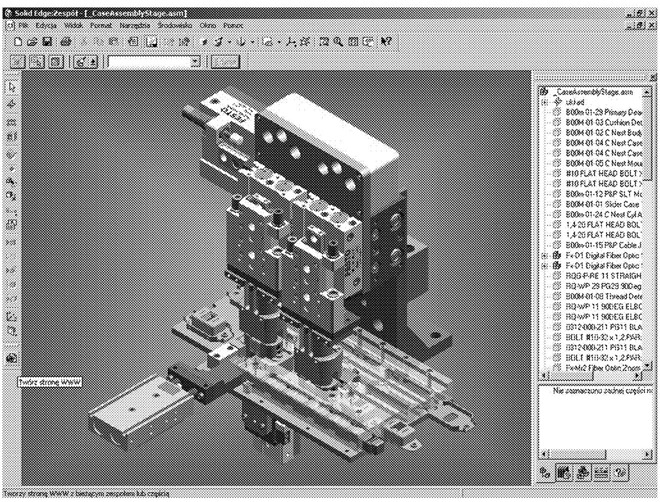

Fig.1: Example of an assembly created using NX system solid edge

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neers to work concurrently. In practice, it is thus possible to make strength and kinematical calculations, or other analyses and simulations simultaneously at certain stages of the model's completion. Design engineers can compile drawings concurrently with project engineers, while the process planning engineers can prepare NC programs. **Master Model Concept** enables unambiguous changes to be made in all related activities. It means that the model is a determinative element in which are carried out all modifications those are to be subsequently transferred to all their respective applications.

Solid Modeling to create basic geometric elements or structural elements of various shapes is the basis of 3D modeling in NX. These elements are parametrically controlled. NX enables the users to create user structural elements and libraries thereof to get the frequently used model parts automated.

Freeform Modeling to create parametric and associative general shapes that can be developed in the form of areas or volume models is likewise fully integrated. It is taken for granted that there are tools indented for creating, editing, smoothing and analyzing the curves and areas.

Direct Modeling also enables the user to modify dimensions and shapes for the models imported from other CAD systems (non-parametric and with no history). If, for example, the user desires to displace a hole, then he/she should only define using geometrical conditions how he/she wants to place that hole, without being limited in any manner whatsoever by the way in which the given hole was created.

2. Creation of a coil parametric model

In general, the coil represents a geometrically complicated body (Fig. 2). Thus, it is not easy to create a parametric model of the coil. There are many areas requiring due attention in order to avoid creating a model that, with a change in certain parameters, will cease to fulfill its function.

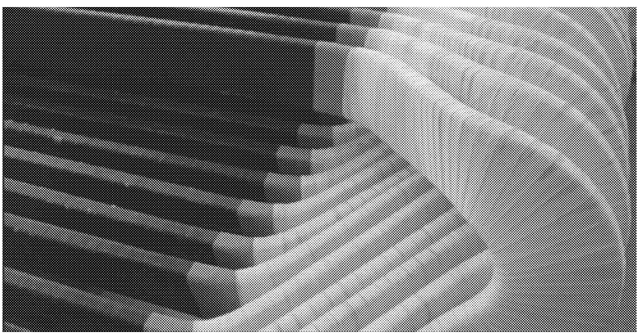

Fig.2: Shaped coil of stator winding

The coil consists of several parts to be dealt with in detail on Fig. 3.

The coil active parts are placed in slots and usually wound with slot insulation. For a direct slot, it is a planar portion of the coil that is parallel to the axis of the stator bundle, while for a skewed slot, it is a portion displaced by *slot skewing* (the coil axis is not identical to the stator bundle axis).

The parametric description of coil active parts depends primarily on the stator inside diameter, number of stator slots, number of poles, coil pitch, number of threads, number of

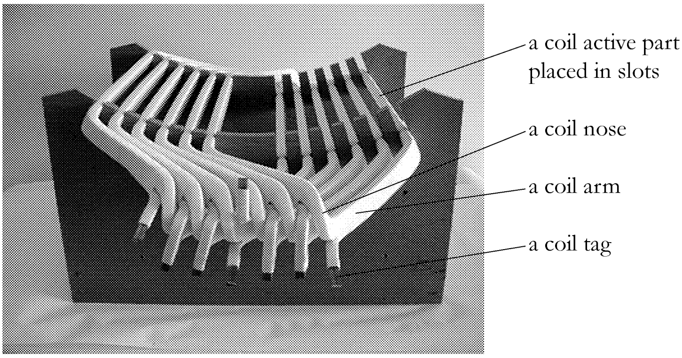

Fig.3: Parts of the stator winding coil

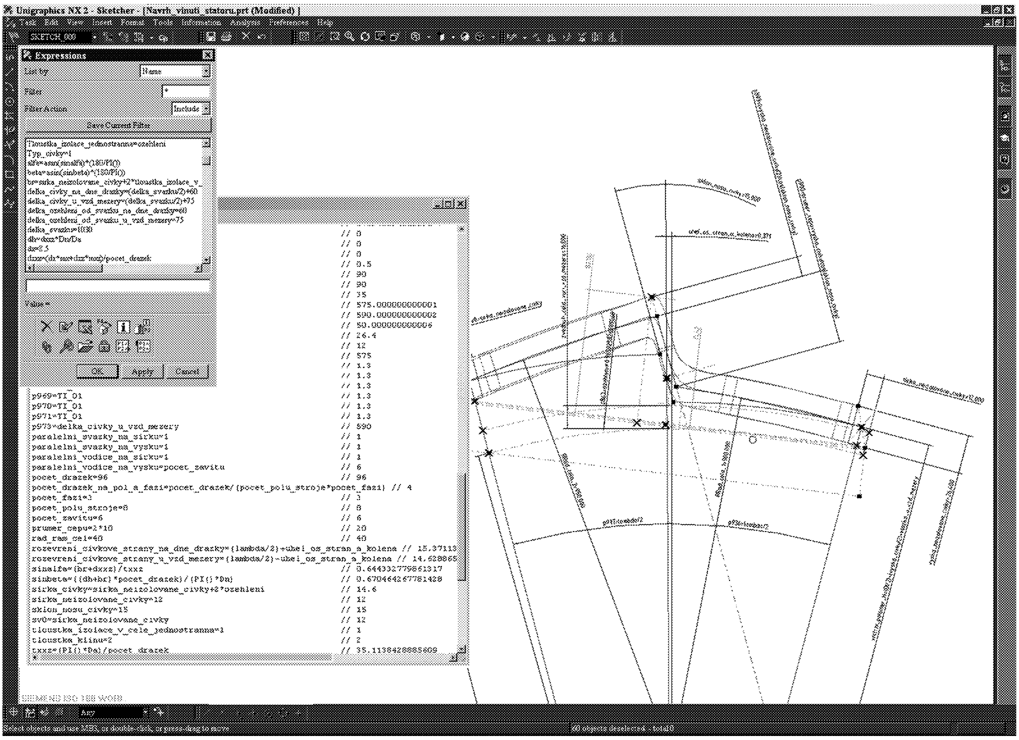

Fig.4: Parametric design of an active coil part

parallel conductors, conductor dimensions, length of the stator bundle, slot lining, coil sides opening and, last but not least, on the shaping pin radius. Using these parameters (Fig. 4), it is possible to set various modifications to control the whole model. For the active part designing, it primarily covers the determination of a proper position of coils in the stator, taking into account the slot lining.

Coil arms connect the active part with the coil nose. It is not a linear connection, but a connection through a non-planar curve in order to place the coils in the stator bundle and to ensure an appropriate distance between adjacent arms.

The parametric model provides a transition between the active part and the coil nose using designed non-planar curves based on control drafts. In this case, two control drafts are available; one has already been used as a basic draft when designing the part placed in the stator slot, while the other is created using the curves resulting from the top view of the actual coil. In other words, the other draft determines a transient radius and an angle of arm inclination considerably affecting the coil overhang shape.

The designed spatial curve is shown on Fig. 5. Using the length of this curve, it is possible to exactly determine the dimensions of the hairpin to be used in the manufacture of that coil. Every point of this curve creates a geometric centre of the coil; thus, it can be used for processing in other programs, in an ideal scenario for an insulation winding machine. Speaking about an ideal scenario means that it is not practically possible to form two absolutely identical coils and, therefore, an identical trajectory is not ensured for each coil.

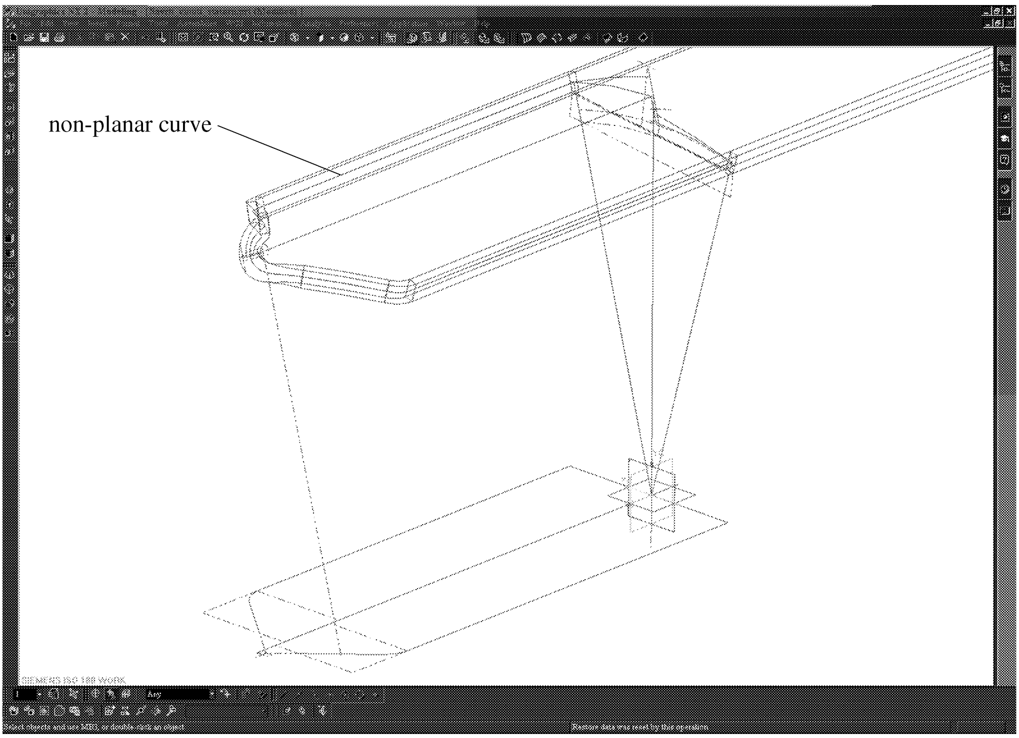

Fig.5: Parametric design of coil arms

The coil nose is usually placed outside the axis of the coil itself to eliminate the impairment of some layers of basic insulation of conductors during formation. Therefore, it is necessary to determine the angle of nose inclination, including the angle of nose axis inclination in order to obtain the same ratio of length for both the arms. Through the amount of nose torsion it is possible to affect the resulting length of the formed coil. Nose torsion has also considerable effect on overhang cooling, because it affects the spacing between individual arms of adjacent coils, a thus the air flow at the coil overhang.

The coil arms and the coil nose create '*coil overhang*' (Fig. 6). The coil overhang represents a coil part showing the greatest losses and a region subject to great thermal stress. Therefore, both the winding temperature and suitable insulation are sized according to coil overhangs (nose torsion, in particular), and not according to the active part that is partially cooled by the slots, in which they are placed. The coil overhang should feature such a shape that will enable its cooling without any special design modifications of the coil and a trouble-free placement of the given coil in the bundle. The overhang shape and size (nose shape in particular) are considerably affected by the type and thickness of the insulation that is used for the entire region. Fig. 7 shows a coil part sectional view with indication of several insulation layers of the coil.

Conductor insulation separates the adjacent conductors of one coil. Due to the fact that the coil comprises more threads, the conductor insulation has a great influence on the total coil size. From the design point of view, it is required to use as small insulation thickness as possible. Nevertheless, the coil should be resistant to many electrical and mechanical effects to be encountered both in manufacture and during operation. From various points of view, the selection of suitable insulation for coil overhangs is the most important element when developing the insulation system.

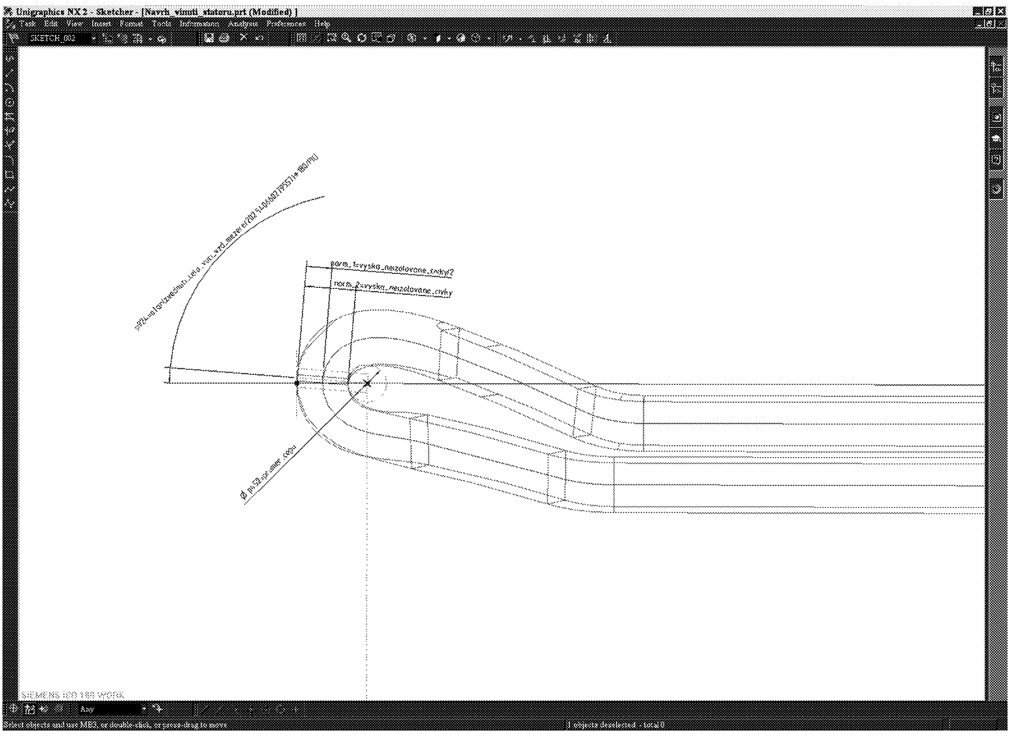

Fig.6: Parametric design of coil nose and nose inclination

Insulation systems for low-voltage machines consist of conductor insulation, slot insulation, and an impregnant. The conductor insulation consists of paint (enamel), a cotton braiding or wrapping, fiberglass, or a combination of solid and deposited insulations. The slot insulation is made from slot board or aramid paper combined with a polyethylene terephthalate foil. This foil is frequently combined with other materials, with glass fabric, a polyester mat and mica paper.

The combination of layered slot insulating materials depends on the machine voltage and maximum operating temperature. The winding is most frequently impregnated by dipping in a vacuum or by dripping. Impregnating varnishes are based on polyesters or polyesterimids.

High-voltage insulation systems indented for rotating electrical machines are manufactured using two technologies. Both of them have advantages, as well as disadvantages. The first method called **RR** – *Resin Rich* is based on the use of resin. The second method called **VPI** – *Vacuum Pressure Impregnation* is based on vacuum pressure impregnation.

The insulation of coil overhangs should withstand not only the stress under operating conditions but also the stress during the winding manufacture. There is usually a conical or a gradual transition between the slot part and the coil overhang insulations; the trend towards machined coil winding has resulted in insulating the coil overhangs with a fixed tape and the coil noses with a flexible tape. The thickness of the coil overhang insulation usually ranges from 60 to 100 % of the main insulation thickness.

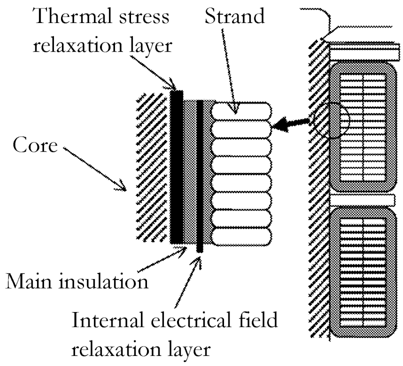

Fig. 7: Detail of stator coil insulation layers

RR insulation system

It is a three-component system consisting of a basic insulating pre-impregnated material containing 30–40 % of bonding agent. During its processing, a compact insulation tube with the required wall thickness is created on conductive parts. The winding parts created in this manner are placed in the machine slots. Glass fabric with a thickness of 0.12–0.14 mm forms a supporting part. Calcined mica paper (made from mica waste) is used as an electrical barrier. Reactoplastic solvent-free epoxy resin is most frequently used as a bonding agent to bind both components.

The material is pre-cured and its thickness ranges from 0.15 to 0.2 mm. It is wound either continuously when multiple tape layers (usual width of 20 mm) are being wound along the entire length of bar or coil up to the required thickness, or discontinuously, when straight portions are being wound with a wide strip that follows the tape wound on the skewed ends of the front portions. In both cases the curing is carried out in moulds where the required pressure and temperature are maintained (160–170 °C).

VPI insulation system

It is a system where absorptive mica tape is used as a basic material to be soaked with an impregnant during the impregnation process. It is most frequently used for traction motors where an impregnation system with excellent insulation and thermal properties is required to reinforce the winding.

The absorptive insulant is mostly used in form of a tape once more consisting of three components. Glass fabric or polyester web is used as a carrying component. The second component consists of non-calcined mica in form of mica paper. Bonding agent content amounts only to 7 %, as a maximum, to ensure mechanical processing of the tape. Material absorption capacity is of prior importance. Solvent-free epoxy, polyester or silicon resins with a dry matter content amounting to 100 % are used as impregnates.

The coils are wound with multiple but continuously overlapping layers. The impregnation plant consists of a pressure-and-vacuum-proof chamber fitted with heating and cooling equipment, and a tank. The impregnation process itself begins by drying at a temperature above 100 °C. After the material has been placed in the impregnation plant, it is vacuumed and soaked with varnish. Subsequently, with the vacuum removed, it is subject to positive pressure. With the varnish discharged and dripping completed, the components are transported to a drying room. Varnish is dried at moderate negative pressure. Curing itself is made in a flow of hot air at normal pressure.

Based on the application as above, we have created a stator coil model in the Unigraphics/NX program that is controlled using 192 parameters. Some of them serve only as geometrical elevations, which enable the measurement of quantities that are otherwise measurable only with great difficulties, without using mathematic expressions. The advantage of these parameters rests on the accuracy with which they are measured from the model; **they are not calculated** (e.g. overhang length, outside coil height, mean conductor length, etc.).

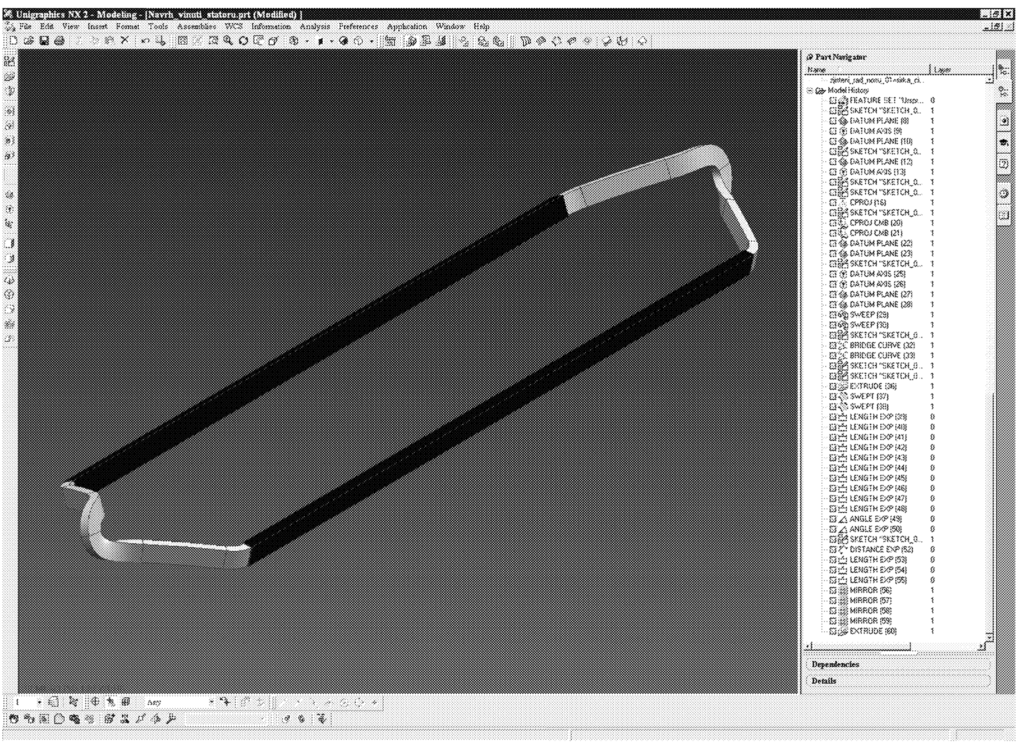

Fig.8: Resulting parametric coil model in NX environment (RR insulation system)

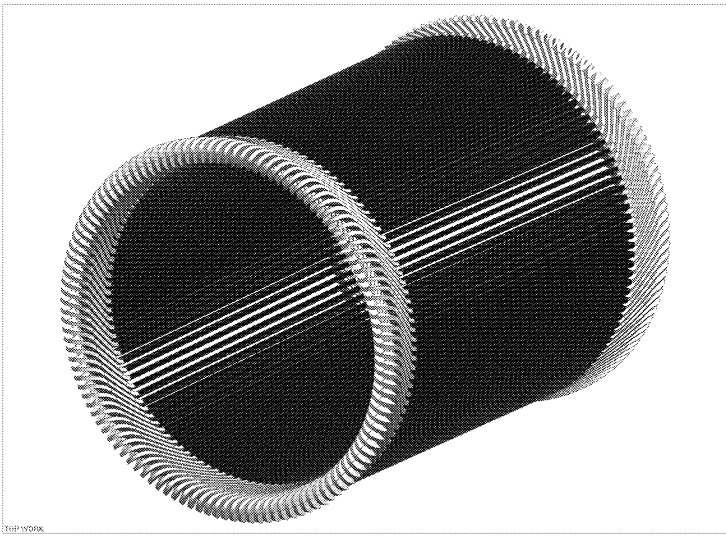

Fig.9: Stator winding of formed coil

A set of stator coils can be created from the already formed coil by inserting the coils into the stator bundle, keying and the required connection. Now, it is possible to see the use of some parameters (Fig. 9) which ensure insulation distances between individual components, i.e. not only for adjacent coils, but which had to be taken into account at the beginning of the model creation. Control parameters for the front arms that affect more adjacent coils are of prime importance because it is necessary to ensure a constant insulation distance, if possible, along the entire arm region, or greater.

3. Linking Unigraphics/NX program to Excel

Fig. 10 shows a variant of changes in parameter setting directly in the NX environment – Toolbar **Expression** (parameter creation, parameter renaming, display of information on a particular parameter and of the relationship of individual parameters, and the possible export and import to external databases). Only one filter can be applied to one parameter in toolbar at a time. The use of this variant to edit more parameters, which applies to us, is not particularly effective.

A spreadsheet is the second variant that can be used for getting all parameters edited at the same time. This is an Excel space and integral part of the NX model; thus, it can be edited only in NX. Spreadsheet does not enable any bulk renaming of parameters, because such renaming destroys links between parameters, and a parameter so renamed will become independent and quite useless, and have no control functions any more. This variant is more practical to use for overwriting the parameter expression where no renaming but further linking to other parameters takes place.

Another advantage of this variant rests on its work space, because it contains not only standard elements and functions like Excel but also other special functions needed for parameter updating within Expression and Spreadsheet Toolbars. Its disadvantage lays in the fact that the given Spreadsheet does not create a conventional file with **.xls** suffix, but it is saved as a work space in the parametric model (or only as a work space with **.xlw** suffix).

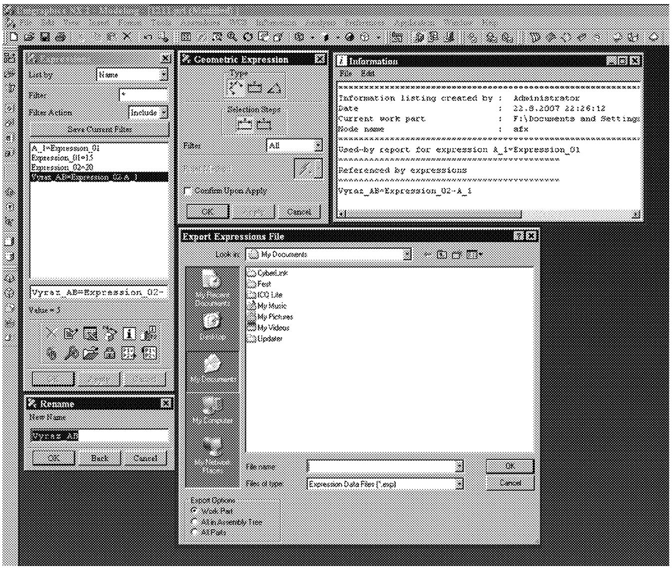

Fig.10: Expression – modifying parameters directly in NX

This is a disadvantage for the user without NX support. But for NX users it is more like an advantage, because they are provided with the Solid Edge system response to parameter changes made, or warned, if an error in parameter entry occurs.

4. Conclusion

Coil forming is associated with many other issues that are not described in this article, nevertheless they are necessary for the proper functioning of a forming machine. Individual programs of forming machines are one of the greatest problems, because their producers and types are different. Therefore, emphasis is also placed on the data to be entered in the programs.

Parameters, used data, program lists (including the description of their functions) and detailed drawings of the coil structural components are not listed here because of copyright protection!

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