Сибирский федеральный университет
Siberian Federal University

Год образования в Содружестве Независимых Государств

# Проспект Свободный-2016

Международная конференция студентов, аспирантов и молодых учёных

# Электронный сборник материалов международной конференции студентов, аспирантов и молодых учёных **«Проспект Свободный-2016»**, посвящённой Году образования в Содружестве Независимых Государств

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# «Implementation of CAD/CAM/CAE Systems»

УДК 620.172/.178.2

# COMPUTER-AIDED DESIGN OF MOLDS

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**Introduction**

At the present time the issues, related to the development of specialized applications is that decision of applied engineering problems and CAD integration, the PDM and ERP in order to create a unified information system of the enterprise. Application integration is more complex challenge than the traditional data integration, often used by IT companies in the implementation of information systems.

**Relevance of the work and objectives of the study:**

In the production of plastic products there are a number of problems:

1) Compaction homogeneous, dense compacts with a uniform distribution of phase components by volume.

2) The emergence of interparticle adhesive bonds, the interparticle friction and border friction on the surfaces of mold inserts.

3) Local gradients in density and high internal residual stresses, larger values of spring back, the unevenness magnitude of shrinkage during cooling and as a result of warping, cracking or even destruction of the compacts, the violation of the accuracy of the size and shape of the deviation and non-compliance with the requirements and tolerances.

The aim of the research work: Improving the quality of products from plastic by providing structural homogeneity in terms of material (to minimize residual stresses, density fluctuations, porosity, micro-cracking, etc.).

Research Project: Plastic materials and products; multi-cavity molds for injection molding machines with a screw feed powder material.

Research Subject: Structure and properties of plastic products.

**The objectives of the study are:**

1) Development and verification of a mathematical model of the process material in molding products difficult-contour profile;

2) Analysis and calculation of temperature fields in the area of formation, taking into account the constructive elements of the performance of heating and cooling channels;

3) sealing process optimization due to configuration changes and local changes in forming the surface and cross-sectional area of the feeding channels (sprues);

4) Development of recommendations on the modernization of the design heating and cooling system to ensure uniformity of heat flows in the forming mold planes;

5) Development of control programs and the technological process of manufacturing multi-cavity molds.

**Development process of manufacturing a multi-die by means of extrusion.**

Let us consider the main stages of development:

1. The drawing of the mold profile (obtained from the company). It is necessary to analyze and disassemble to build a 3D model of the mold.

2. Analysis of the types of profiles of plastic products Development of the geometric profile (calculation of automation and simulation 3D model of the profile of the die).

3. The development of a composite material for the mold (the selection ratio of the components of the composite).

Designed composite must meet the strength characteristics of the mold.

4. Finite element calculation of the flow of material through a die (extrusion process simulation).

At this stage, the material flow calculation performed through a die and its solidification in the mold.

**Program**

The developed software supports SolidWorks 2015 x64. The developed program will be implemented by the calculation of geometric parameters of the die, and the program will be developed algorithm simulation 3D model of the die.

**Calculation of molds of different geometries.**

Briefly program - a module for calculating the geometry and construction of the mold with a different geometry. It can transfer model in CAD SolidWorks system.

The program's interface is shown in Figure 1. The program calculates the height of the compact, the height of the loading chamber, the size of the mold cavity (window) of the matrix, the rod size, punch size. The program will add a geometric calculation die under the profile of the mold, die build 3D models in SolidWorks.

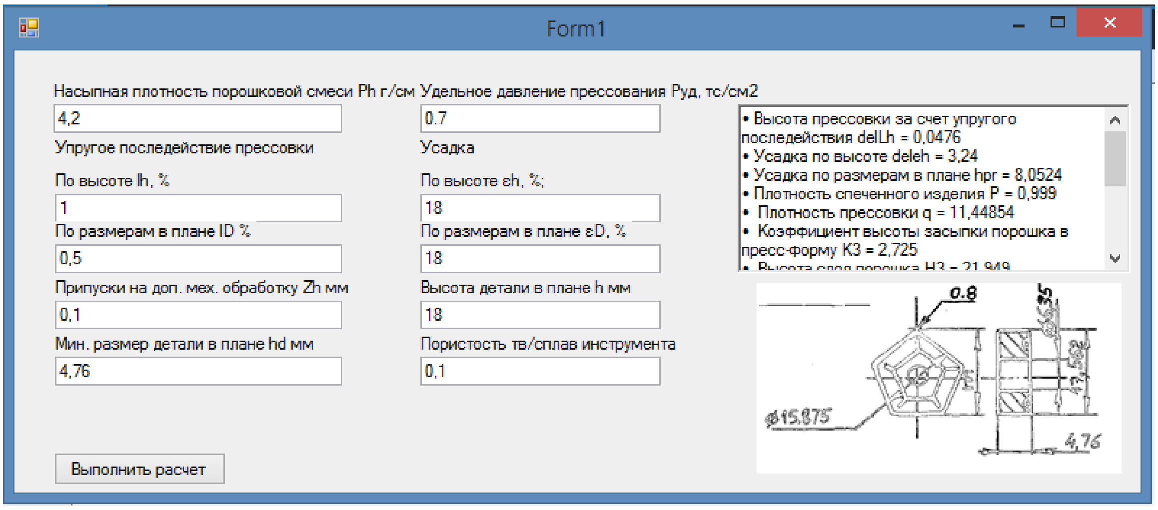


***Fig.1 - Window dimensioning molds***

When calculating and designing molds executive sized main data characterizing the technological properties of powders and compacts are:

• Bulk weight (bulk density) of powders
• The share of the compact powder (density)
• Elastic aftereffect
• Shrinkage during sintering

Here is the algorithm for calculating the mold (Figure 2) for the manufacture of hard metal tool plate.

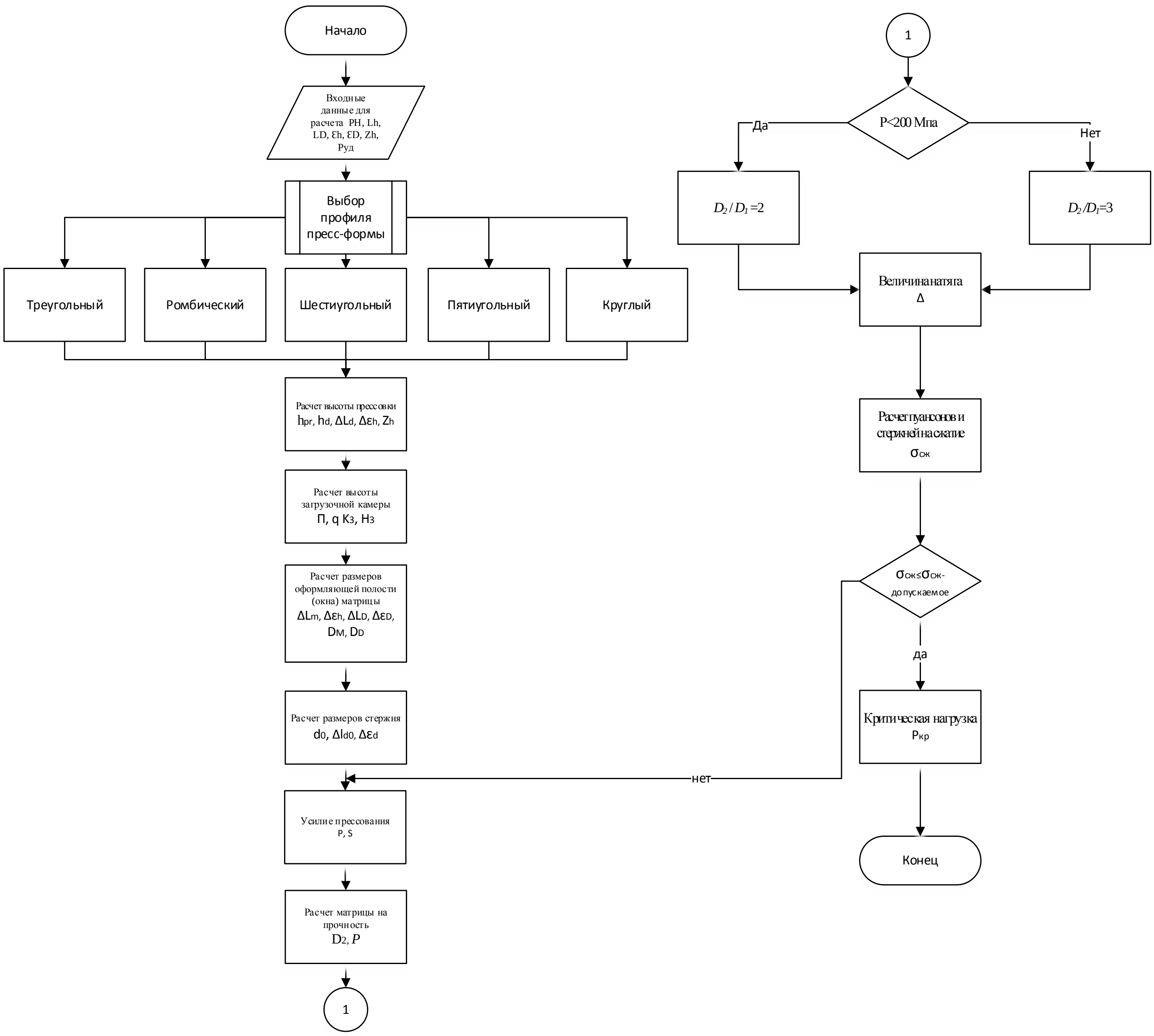


***Fig.2 - Algorithm for calculating the mold profile***

**Calculation of mold for the manufacture of hard metal tool plate**

Here are the basic formulas for calculating the mold.

1) Calculation of the compact height

To determine the height of the pre-pressing recalculate its height changes as a result of the spring back forces from the formula:

$$\Delta l_h = \frac{l_h \cdot h_d}{100} \quad (1)$$

Similarly, the recalculated value changes as a result of pressing the height of shrinkage during sintering the formula:

$$\Delta \varepsilon_h = \frac{\varepsilon_h \cdot h}{100} \quad (2)$$

Pressing the height adjustment calculation is reduced to its size, which should compensate for the shrinkage and spring back, until the required parts:

$$h_{pr} = h_d - \Delta l_h + \Delta \varepsilon_h + z_h \quad (3)$$

2) Calculate the height of the loading chamber

Given that the total porosity carbide tools should not exceed the value of 0.1% by the formula density of sintered body:

$$\Pi = \frac{100 - \Pi_0}{100} \quad (4)$$

The compaction is determined by the formula (5):

$$q = \Psi \cdot \Pi \quad (5)$$

Height ratio of the powder filling into the mold defined by the relation:

$$K_3 = \frac{q}{p_H} \quad (6)$$

A filling height (i.e., height of the powder layer, which is necessary to obtain compact high $h_{pr}$ ) calculated by formula (7):

$$H_3 = h_{pr} \cdot K_3 \quad (7)$$

3) The calculation of the size of the mold cavity (window) of the matrix

Pre recalculated changes in terms of compact size due to shrinkage during sintering and spring back by formulas (8,11):

$$\Delta l_m = \frac{l_m \cdot m}{100} \quad (8)$$

$$\Delta \varepsilon_h = \frac{\varepsilon_h \cdot h}{100} \quad (9)$$

$$\Delta l_D = \frac{l_D \cdot D}{100} \quad (10)$$

$$\Delta \varepsilon_D = \frac{\varepsilon_D \cdot D}{100} \quad (11)$$

The dimensions of the matrix determined by the formula (12)

$$D_M = d_{iHM} - \Delta l_{di} + \Delta \varepsilon_{di} - z_{di} \quad (12)$$

$d_{iHM}$ = the smallest size of the finished product (the lower boundary of the tolerance) mm;

For size D (matrix)

$$D_D = d_{HM} - \Delta l_d + \Delta \varepsilon_d - z_d \quad (13)$$

For size m (matrix)

$$D_m = d_{HM} - \Delta l_m + \Delta \varepsilon_m - z_D \quad (14)$$

4) The calculation of the size of the rod

The calculation is performed similar to the definition in terms of the formula matrix sizes (15):

$$d_0 = d_{0HM} - \Delta l_{d0} + \Delta \varepsilon_{d0} + z_{d0} \quad (15)$$

$d_{OHB}$ - the largest size of the holes in parts (the upper boundary of the tolerance);

Spring back and shrinkage, respectively, the size of the holes in the part, mm; calculated as follows (16,17):

$$\Delta l_{d0} = \frac{l_{d0} \cdot d}{100} \quad (16)$$

$$\Delta \varepsilon_{d} = \frac{\varepsilon_{d} \cdot d}{100} \quad (17)$$

Calculated data obtained in the program have the same meaning as in the methodological guidelines for computation of molds.

**The results**

The work program was designed to calculate the execution of molds sizes. As a program for the construction of the mold is chosen SolidWorks. The program will be able to simulate a 3D model of the die.

Experience in the development of this program, as well as market analysis of the existing programs have allowed the following conclusions:

- All software developers seeking to facilitate the construction of mechanisms for their own CAD-programs, creating for them the application of building the program.

- Due to the small number of such applications should take into account their limitations to create your own program. The main drawback of such programs is most geometric construction of all the known parameters, that is necessary to transfer all the calculations manually.

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# THE SCALING MODEL OF THE WIND TURBINE DESIGN COST

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When evaluating any change to the design of a wind turbine, it is critical that the designer evaluate the impact of the design change on the system cost and performance. The work described in this document is an attempt to develop such a model, in a spreadsheet format, that can be used by designers to look at the impact of scaling and configuration on overall COE. The study was not designed as optimization study, but was structured to identify barriers to size increase It would be difficult for a user to exercise the model in an optimization mode without taking into account the innovation that could be applied to the design of many of the major components to reduce the size, mass and cost as they increase in rating.

The DOE/NREL scaling model [1] is a spreadsheet-based tool that uses simple scaling relationships to project the cost of wind turbine components and subsystems for different sizes and configurations of components In most cases, cost and mass models are a direct function of rotor diameter, machine rating, tower height, or some combination of these factors. The results of each model are assumed to be in 2002 dollars. Cost data is based on a mature design and a 50 MW wind farm installation, with mature component production.

Cost of Energy (COE) is calculated using the following equation: COE – levelized cost of energy ($/kWh); FCR – fixed charge rate (constant $) (1/yr); ICC – initial capital cost ($); $AEP_{net}$ – net annual energy production (kWh/yr); AOE – annual operating expenses; LLC – land lease cost; O&M – levelized O&M cost; LRC – levelized replacement/overhaul cost.

The fixed charge rate (FCR) is the annual amount per dollar of initial capital cost needed to cover the capital cost, a return on debt and equity, and various other fixed charges The initial capital cost is the sum of the turbine system cost and the balance of station cost. Neither cost includes construction financing or financing fees, because these are calculated and added separately through the fixed charge rate. The costs also do not include a debt service reserve fund, which is assumed to be zero for balance sheet financing. The PPI categories and the associated NAICS codes are detailed below for each wind turbine component listed in the baseline cost estimate Baseline blade material cost.

Advanced blade material; Blade assembly labor cost; Hub; Pitch mechanisms and bearings; Low-speed shaft; Bearings; Gearbox; Mechanical brake, high-speed coupling, etc.; Generator (not permanent-magnet generator); Variable-speed electronics; Yaw drive and bearing; Main frame; Electrical connections; Hydraulic system; Nacelle cover; Control, safety system; Tower; Foundations; Transportation; Roads, civil works; Assembly and installation; Electrical interface and connections (cost established based on transformer at 40%)

The model does not provide for any attempt at projecting commodity costs into the future. The General Inflation index identified here is based on the Gross Domestic Product. The GDP numbers are updated yearly. As additional information is obtained, these breakdowns and NAICS assignments may be adjusted.

Blade mass and cost:

$$M_{blade} = 0.1452 \cdot R^{2.53} = 0.405\ kg$$
$$Cost_{\ blade} = M_{blade} \cdot Cost_{1kg} = 1519\ \$$$

where $R$ – rotor radius is 1.5 meters;

$Cost_{1kg}$ *– cost of 1 kg of fiber.*

Hub mass and cost:

$$M_{hub} = n \cdot 0.954 \cdot M_{blade} + 56.3 = 57.5\ kg$$
$$Cost_{hub} = M_{hub} \cdot 4.25 = 245\ \$$$

where $n$ – number of blades.
Total pitch bearing mass:

$$M_{bearing} = 0.1295 \cdot M_{three\ blades} + 49.31 = 50\ kg$$

Total pitch system mass and cost (three blades):

$$M_{bearing\ system} = (M_{bearing} \cdot 1.328) + 55.5 = 121.2\ kg$$
$$Cost_{bearing\ system} = 2.28 \cdot (n \cdot R \cdot 2)^{2.6578} = 783\ \$$$

Nose cone mass and cost:

$$M_{nose\ cone} = 18.5 \cdot R + M_{hub} = 85.2\ kg$$
$$Cost_{nose\ cost} = M_{nose\ cone} \cdot 5.57 = 475\ \$$$

Low-speed shaft mass and cost:

$$M_{low-speed\ shaft} = 0.0142 \cdot R^{2.888} = 0.05\ kg$$
$$Cost_{low-speed\ shaft} = 0.01 \cdot R^{2.887} = 0.03\$$$

Bearing mass:

$$M_{bearing} = \left(R \cdot \frac{8}{60} - 0.033\right) \cdot 0.0092 \cdot R^{2.5} = 0.04\ kg$$

Total bearing system mass:

$$M_{bearingSys} = 2 \cdot M_{bearing} \cdot 17.6 = 0.15\ kg$$

The generator should be chosen from the list below:
Three-stage planetary/helical gearbox mass and cost:

$$M_{three-stage} = 70.94 \cdot LSpeed_{shafttorque}^{0.759}$$
$$Cost_{three-stade} = 16.45 \cdot MacRating^{1.249}$$

Single-stage drive with medium-speed generator mass and cost:

$$M_{single-stage} = 88.29 \cdot LSpeed_{shafttorque}^{0.774}$$
$$Cost_{single-stage} = 74.1 \cdot MacRating^{1.00}$$

Multi-path drive with multiple generators mass and cost:

$$M_{multi-path} = 139.69 \cdot LSpeed_{shafttorque}^{0.774}$$
$$Cost_{multi-path} = 15.26 \cdot MacRating^{1.249}$$

Three-stage drive with high-speed generator mass and cost:

$$M_{three-stage} = 6.47 \cdot MacRating^{0.9223}$$
$$Cost_{three-stade} = 65 \cdot MacRating$$

Single-stage drive with medium-speed, permanent-magnet generator mass and cost:

$$M_{single-stage} = 10.51 \cdot MacRating^{0.9223}$$
$$Cost_{single-stage} = 54.73 \cdot MacRating$$

Multi-path drive with permanent-magnet generator mass and cost:

$$M_{multi-path} = 5.34 \cdot MacRating^{0.9223}$$
$$Cost_{multi-path} = 48.03 \cdot MacRating$$

Three-stage drive with high-speed generator mass and cost:

$$M_{MAINthree-stage} = 2.233 \cdot R^{1.953}$$
$$Cost_{MAINthree-stade} = 9.489 \cdot R^{1.953}$$

The direct-drive approach has no gearbox and it has the highest performance, so the permanent magnets generator was chosen [2].

Direct drive mass and cost:

$$M_{direct\ drive} = 661.25 \cdot LSpeed_{shafttorque}^{0.606} = 164\ kg$$
$$Cost_{direct\ drive} = 219.33 \cdot MacRating^{1.249} = 220\ \$,$$

where $MacRating$ – power capacity of the wind turbine is 1 kW.

Variable-speed electronics total cost:

$$Cost_{variable-speed} = 79 \cdot MacRating = 79\ \$$$

Electrical connection cost:

$$Cost_{electrical} = 40 \cdot MacRating = 40\ \$$$

Hydraulic, cooling system mass and cost:

$$M_{HCSys} = 0.08 \cdot MacRating = 0.08\ kg$$
$$Cost_{HCSys} = 12 \cdot MacRating = 12\ \$$$

Nacelle cover cost:

$$Cost_{nacelle} = 11.537 \cdot MacRating + 38.7 = 50\ \$$$

Nacelle entire mass:

$$M_{nacelle} = \frac{Cost_{nacelle}}{10} = 5\ kg$$

**Conclusions**

Costs used to develop scaling curves in these models are based on 2002 dollars. Where data from other periods have been incorporated into the data for evaluating the scaling curves, they have been deescalated using the Producer Price Indexes (PPIs) described below.

To compensate fluctuations and to accurately project the cost of components into out years, a component cost escalation model was developed based on the PPI. The PPI was scoured for categories comparable to wind turbine components. In some instances, a wind turbine component is represented by a composite of several PPI categories. Labor-intensive components such as rotor blades and electrical interface components include a labor cost escalator, which was specified as the general inflation index, based on the Gross Domestic Product (GDP). Other components, such as the hub, are delivered in an essentially finished state so it was assumed that labor costs were included in the appropriate PPI category.While this approach allows the escalation of costs from the 2002 baseline date to the present.

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# THE CHOICE OF INSTRUMENTS TO IMPLEMENT A METHODOLOGY DESIGN FGRMONIC DRIVE

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Modern methods of designing the harmonic drives (HD, Fig. 1) based on the choice of the parameters to achieve a desired bearing capacity, the prevention of the interference of the teeth, as well as reducing stress in the flexible gear (FG). However, the method of choice offset coefficient selection method for producing FG and cutting process do not include service features of spacecraft units [2]. Known tools allow to simulate of the interaction undeformed wheel (teeth mesh gap, the angle of the tangent at the contact point of the tooth edges) otherwise require a full-scale experiments [5]. Using a numerical experiment for the analysis of the contact interaction of gear has become widespread in recent times; this is due to the growth of computing power, as well as simplification of modeling and calculation mechanisms. Many of the results are due to a number of domestic authors [1], including contact and interaction in the HD [3]. Foreign researchers also address the question of the state of stress of the FG, which is located on the cam generator [4]. However, these studies not-system and relate to matters fatigue endurance FG, in particular its fillet curve. The questions of the teeth contact of flexible and rigid wheels are not considered.

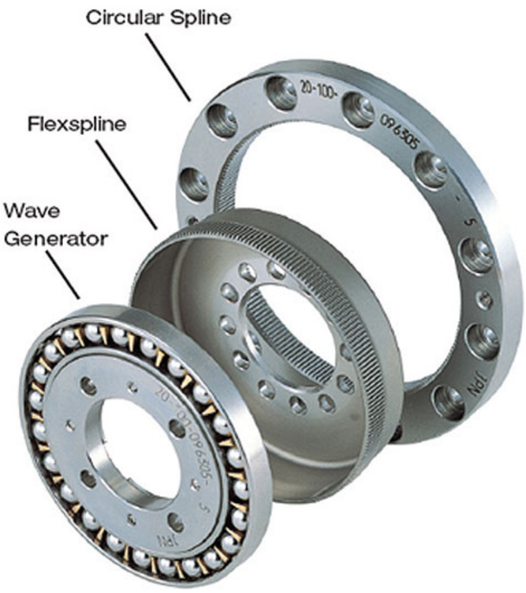


***Fig.1 – Harmonic Drive***

The need to find the values of the contact pressure in the engagement area is primarily concerned with the analysis of the process of wear of the teeth, one of the main causes of failure of the HD because of loss of accuracy and start moment. Search velocity slip values in the contact zone is associated with a different profile of the cam generator, this task does not require mathematical and numerical serious resources. Search contact pressures associated with the construction of a model of a flat flexible engagement and hard external gear. At the same FG must be pre-deformed by a cam that provides the correct stress value estimation in the fillet curve of the tooth.

Using analytical dependencies allows you to select the basic parameters of the HD at an early stage, using criterion or expert assessments. The main difficulty here is the choice of the design parameters in the conditions of use of standard tools and equipment for the production of gears. Therefore, the first phase of the design choice of the number of teeth and the module with the calculated diameter of FG, performed with expert review (takes into account the production and exploitation experience). Using the finite element method (FEM) allows you to confirm the choice of form factors and offset cam profile for engagement zone and the resulting value of the contact pressure at various specific loads [3]. Also important task is to choose the form of the FG, and the different approaches in the design of the HD with form of FG is "cup" or short-GK.

At the figures below (Fig, 2, 3) we see the distribution of contact stresses between teeth. If we see, the maximum value is shifted from zero line by 2-3 digress. This allow us to increase the sliding speed and prevent to micro welding of functional sides of gears.

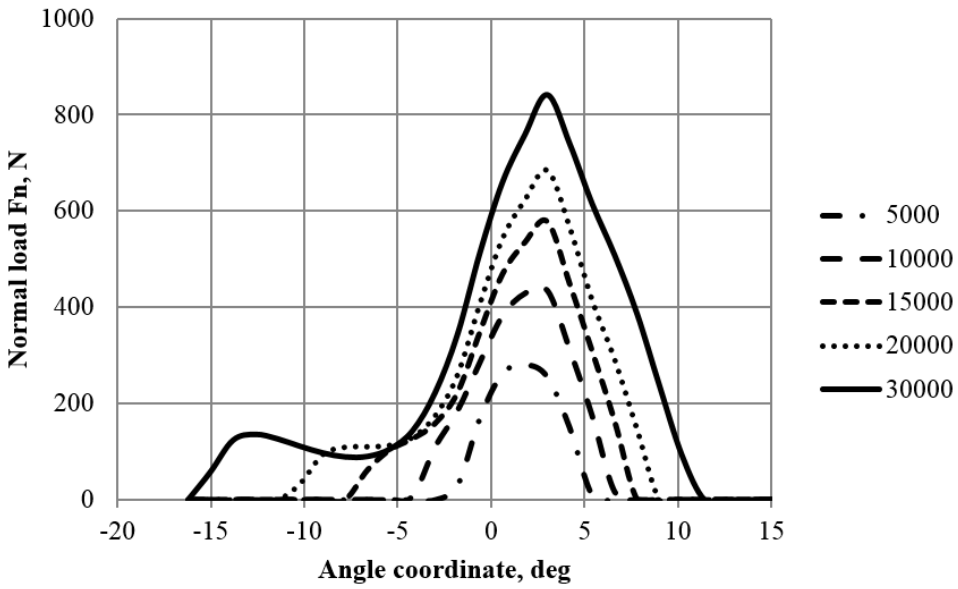


***Fig.2 – Distribution of load between the teeth with different loading on output gear***

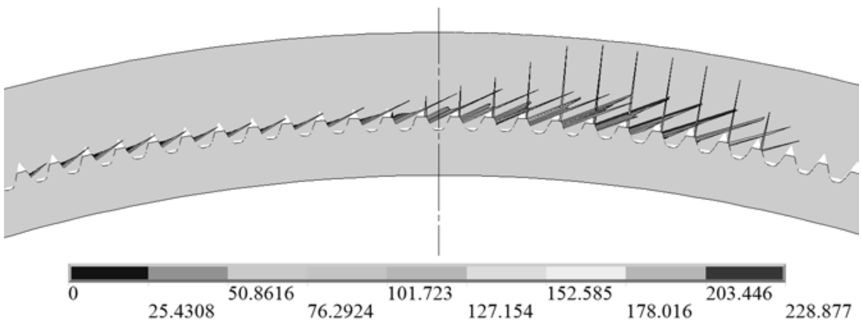


***Fig.3 – The nature of the engagement of the flexible and rigid gear***

The FEM is allow us to variate different geometric parameters of FG. At the figure below (Fig. 4) we see the effect of variation of radial clearance and shell-wall thickness.

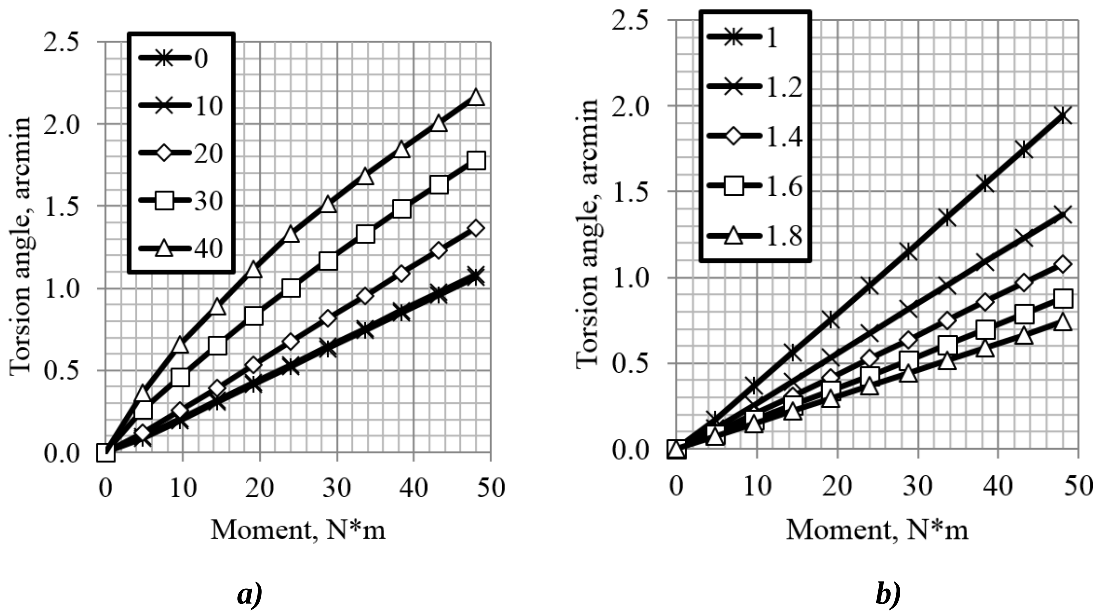


***Fig. 4 - The relation of torsion angle and output moment of the FG, arcmin .: a - variation of the radial clearance between the outer ring of the bearing and FG, microns; b - FG shell thickness variation in the area of teeth, mm***

The use of CAD / CAE packages interaction allows for making the right design decisions, as well as to confirm design decisions in a shorter time. Using open source software package database interface allows you to automate the creation of simulation models if necessary.

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# MODERN GENERATOR TECHNOLOGIES FOR WIND TURBINES

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In this article, different electric generator topologies for wind turbines will be reviewed. For example, the most common generator type used in the small wind turbines is the permanent magnets generator. Some of these designs are direct-drive permanent magnet generators, the doubly-fed induction generators and brushless DC generators.

Mechanical energy captured by the blades converts to electrical energy by a series of components such as gearbox, generator, power electronics and step-up transformer. The generator is the most important component in the power take-off system and there are many different generator topologies depending on the size if the turbine, operating conditions and speed range.

A smaller, lighter generator also enables the nacelle to be transported and lifted to the tower in one piece, which reduces the installation time.

**Doubly-Fed Induction Generator (DFIG)**

DFIG coupled with three-stage gearbox (DFIG-3G) is the most common power take-off system in wind turbines, with more than half of the market share (Fig 1). DFIG generators are usually coupled with multi-stage gearboxes to increase the rotational speed. DFIGs rotational speed is close to the synchronous speed (e.g. 1500 rpm for a 4-pole machine in a 50 Hz grid). In Fig. 1, DFIG wind turbine (1.5 MW) is presented, which are manufactured by General Electric.

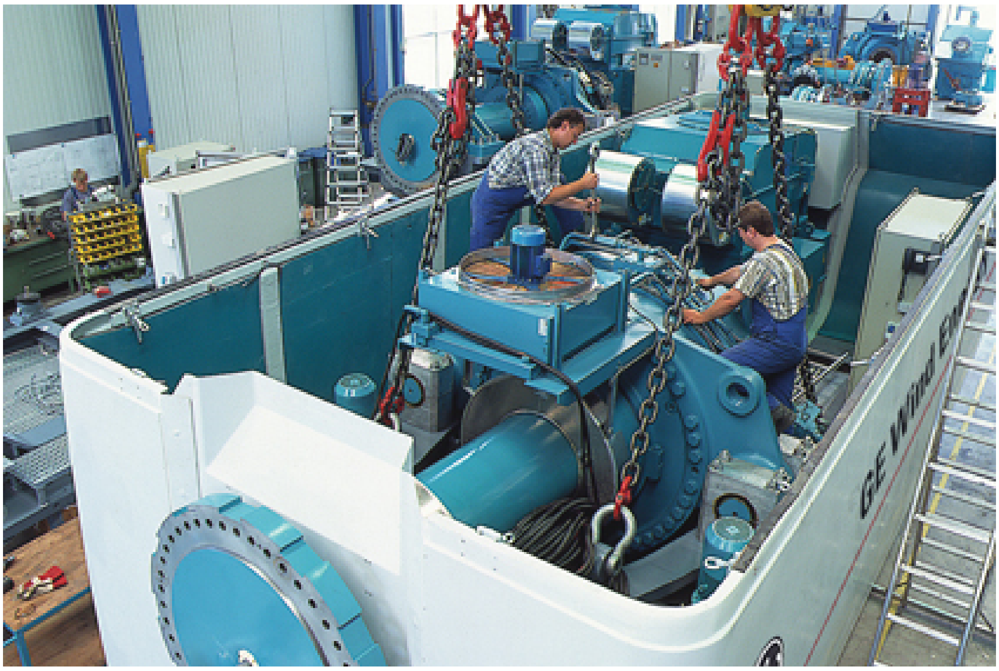


***Fig.1 - DFIG for 1.5 MW wind turbine***

The advantages of the DFIG can be listed as:

– Partially rated power electronics reduces the cost.

– Ability to supply reactive power to the grid.
– Off-the-shelf components, wide range of generator options.

However, DFIGs also have a few disadvantages compared to direct-drive systems [1]:

– A multi-stage gearbox is necessary which may cause reliability issues.
– A slip ring is used, which require regular maintenance.
– High torque peaks in the machine and large stator peak currents under grid fault conditions. The power electronics should be protected.
– In case of grid disturbances, the ride-through requirements make the DFIG control complex.

**Electrically-excited synchronous generators**

Direct-drive electrically excited synchronous generators are similar to conventional synchronous generators with a high number of poles to compensate for the low-rotational speed. The generator has a wound rotor winding, which requires slip rings to excite. The reactive power and generator output voltage can be controlled using the field current. The assembly is easier compared to PM machines as there is no magnetic attraction between rotor and stator. Rare-earth PMs are not used in the generator, so the cost is lower than PM generators. The disadvantages of the generators can be listed as:

– Largest and heaviest generator type.
– Slip rings require regular maintenance.
– Losses in the field winding reduce efficiency.

**PM generators**

Direct-drive PM generators are synchronous generators that have rare-earth magnets instead of a field winding [2]. They became popular in the recent years because of the simple and robust structure [3]. The generator is mounted directly between the nacelle and the blade hubs.

Compared to geared solutions and electrically excited synchronous generators; direct-drive PM generators have the following advantages:

– The generator has no slip rings, which require regular maintenance.
– Having no field winding losses, the generator has a better efficiency.
– PM generators usually have higher torque densities.

However, the drawbacks of the PM generators can be listed as:

– Iron-cored DDPMGs are difficult to assembly because of attraction force between rotor and stator.
– Increased cost because of high price of rare-earth PMs.
– Risk of demagnetization of magnets during short-circuit faults.
– No control over the induced voltage magnitude.

The biggest drawback of PM generators is the high cost of rare-earth magnets, which increased more than tenfold between 2009 and 2011 due to export and mining regulations introduced by China. In Fig. 2, the price variation of Neodymium Oxide is presented. Although the prices of PMs came down after the peak in 2011, they are still volatile and still four times more expensive compared to five years ago.

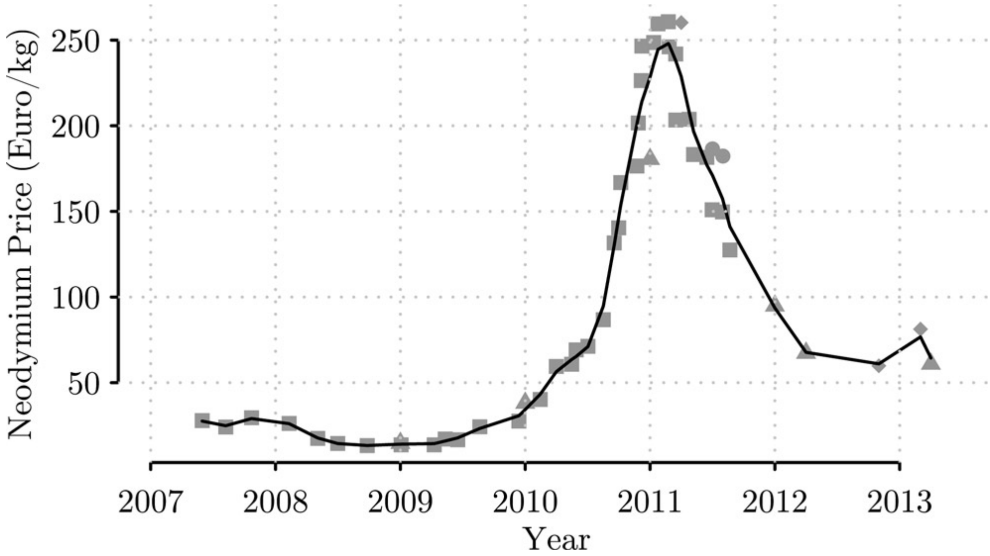


***Fig.2 - Neodymium Oxide price variation between 2007 and 2013 [4]***

It is stated in [5] that the future technologies are in risk because of the high demand of rare-earth metals and supply chain problems because of political risk.

**Conclusion**

In this article, different electrical generator technologies for offshore wind turbines are reviewed. DFIGs are the most common generator type for multimegawatt offshore turbines. DFIGs are off–the shelf and reliable generators, and they have the advantage of using a partial-rated power electronics system, which reduces the overall cost. However, the gearboxes used with DFIGs have reliability problems and require regular maintenance.

Direct drive generator systems, especially PM direct drive systems, became more popular because of the minimum number of moving parts and increased reliability. However, the increasing cost of rare-earth PMs makes the initial cost of the direct-drive systems more expensive compared to geared systems. It is argued that reduced maintenance cost will make them economically more viable.

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УКД: 629.782

# COMPARATIVE ANALYSIS OF THE MODERN OPEN STANDARDS FOR BUILDING BUS-MODULAR SYSTEMS

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This paper contains the results of a comparative analysis of modern open standards for building bus-modular systems. The paper is a summary of the latest open standards, history and prospects of development indicative prices for the system-wide part, a brief comparative analysis of the standards.

Market analysis shows that currently the major open standards to create bus modular systems are standards such as VXI, PXI (PXIe), LXI, AXIe. A brief description is given in Table 1.

**Table 1 – A brief description of open standards**

| Open standard | Short description | Year of creation | Producers |
|---|---|---|---|
| VXI | VXI standard - is an independent standard for test, measurement and control equipment of higher class of accuracy. Based on VMEbus. | 1987 | «VTI Instruments», «Keysight Technologies», «National Instruments», «Holding Informtest», and the other only about 100 manufacturers |
| PXI | PXI Standard - is an independent standard for modular instrumentation. Based on the PCI data bus computer (PCI Express for PXIe) | 1997 | «National Instruments» 90% of market, and the other only about 70 manufacturers |
| LXI | The LXI standard - the standard for industrial network based on standard Ethernet networks, developed and maintained by a nonprofit organization LXI | 2005 | «Aeroflex, Inc», «AMETEK Programmable Power», «VTI Instruments», «Keysight Technologies», «National Instruments», «Holding Informtest», and the other only about 13 manufacturers |
| AXIe | AXIe standard - is the newest standard for building modular instrumentation high-end, based on the AdvancedTCA telecommunications computing architecture | 2010 | «ADLINK Tech. Inc», «Keysight Technologies», «Modular Methods LLC», «Holding Informtest», and the other only about 11 manufacturers |

In any bus-modular system is possible to identify the main elements:

- Crate (chassis);

- Slot 0 controller;
- Functional modules;
- Control computer.

Simplified of bus-modular system is shown in Fig. 1.

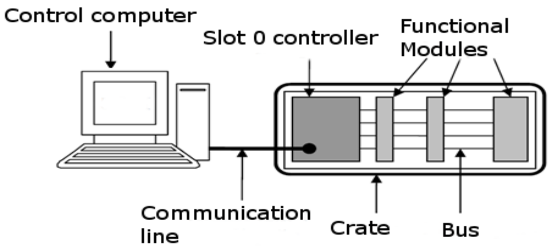


***Fig.1 - Simplified device of bus-modular system***

Crate – a mechanical frame for installing the modules, in addition, are located in the rack: bus, power supply, cooling system. In the case of a large system with a plurality of measuring devices installed in several racks, they (racks) can be mounted in a special rack.

Modules – there are electronic units that perform different functions: measurement, signal generation, storage, conversion and other signal modules are installed in the rack and connected to the bus.

Slot 0 Controller - provides the interface line and the external computer.

Control computers - can be used two types of external computers (industrial or normal PC) or a computer having a constructive open standard and combines the functions of the controller slot 0.

For evaluation, table 2 shows the approximate prices for major components of systems.

**Table 2 - Equipment prices**

| **Equipment** | **Bus modular system** | | | |
|---|---|---|---|---|
| | **VXI** | **PXI** | **AXIe** | **LXI** |
| Crate or carrier | Rack VXI 3.0 13-slots, $ 7.000 | Chassis PXI 18-slots, $ 5.000 | Crate Agilent M9514A AXIe 14-slots, $ 38.000 | MezaBox LXI for 4 mezzanine modules, $ 8.000 |
| The control computer (built-in type) | VXI Embedded PC (Intel Core i5), $ 7.000 | High embedded controller PXIe M9037A, $ 6.950 | AXIe Embedded PC Controller M9536A, $ 9.400 | Any computer (laptop) can be used as a control computer |

For VXI device specified price in Russia, as there are Russian producers. For devices from other manufacturers price listed abroad, that is, the price is still necessary to allow the import duty on the equipment.

**Advantages of VXI:**

- Open standards to support a very large number of equipment manufacturers maximizes flexibility and reduces system obsolescence factor;
- The range of modules is constantly expanding. Technical characteristics of the equipment improved;
- Standard Specification updated and upgraded;
- Increased system performance reduces the measurement and testing and expands the functionality;

- The smaller size and greater density of arrangement reduces the space needed to install equipment, make it more mobile and easier to access the test or control device;
- Precise timing and synchronization improve measurement capabilities of the system;
- Standardized software VXIplug & play simplifies and accelerates configuration, programming and system integration;
- Tough modular design improves reliability, increases mean time between failures and reduce the mean time between repairs;
- VXI Technology allows to reduce the costs of maintenance of the system throughout its service life;
- Standard officially recognized in Russia, has its presentation in the form of GOST and GOST RV.

**Advantages of PXI:**

- PXI-products market is constantly growing and developing - just for today, you can expect more than 1150 different measurement modules, with which it is possible to create the equipment that is best suited for your application;
- The architecture of the PC allows you to use high-speed and multi-core processors for use in applications requiring mathematical processing of data and complex analysis;
- Bandwidth PCI - 132 Mb / s, which is 100 times greater than GPIB interface;
- Ability to synchronize clock and allow the use of more closely the implementation of PXI modules, thereby increasing the accuracy of measurements;
- PXI chassis contains up to 17 measurement modules;
- The software has an intuitive interface, as well as other software for personal computers - no need for additional time to study the process of integration of systems and at the same time, and bearing the cost of training employees.
- The main advantage compared to VXI is the lower price of the system components.

**Advantages of LXI:**

- Simplify the creation of systems using LXI bus;
- Automatic identification of the instruments connected to the PC, and configure the interfaces;
- Reduction of overhead costs, reusing existing equipment and software;
- Reduction of the time settings and increase system performance;
- Compatible with measuring instruments with GPIB interface, USB, Eithernet / LAN, RS-232 and of VXI, from various manufacturers;
- Ability to work in a preferred development environment for the user (Agilent VEE Pro, NI LabVIEW, Microsoft Visual Studio, and others);
- Reliable control instrumentation, combined with high performance;
- Reducing the size of the system;
- Troubleshooting system modernization.

**Advantages of AXIe:**

AXIe is a fusion of technical solutions used in all open standards:

- Shielding;
- Large size of the board;
- Mezzanine technology of VXI;
- PCIe and PXIe line from ATCA;
- 1Gb LAN bus of LXI;

- Technology of construction of IVI drivers;
- Constructing architecture and data transmission from the ATCA.

**Disadvantages of open standards**

Shortcomings in the standards under consideration rather difficult to identify, such as VXI and PXI standards in most cases have the same specifications, ie to implement the MMC and can be on and the other standard. But the system is implemented in the VXI standard will be more expensive than in the PXI standard. At first glance, not unimportant fact the price, but:

- With regard to the production in Russia PXI modules and PXI systems, it is virtually non-existent at most 10% of the market. Moreover, if the PXI modules is relatively easy to produce, the main problem is that the system-wide part of the PXI only in the United States and mainly National Instruments. While in Russia there will be a Russian-wide part of the PXI (controllers of its own production, interfaces, racks, software PXI VISA), have all Russian PXI system is based on a system-wide part of the National Instruments on its own terms and for its prices, and depend entirely on the National Policy Instruments;
- The disadvantages include the LXI standard, something that does not yet have Russian GOST - foreign analogues description of the standard and the lack of a large number of companies engaged in production of equipment in the LXI standard;
- The disadvantages of standard AXIe include a sufficiently high price for the components and likewise not a lack of Russian GOST - foreign analogues standard descriptions.

**Conclusions**

- VXI standard is focused on creating accurate and secure control of diagnostic and measurement and control systems. The range of modules is constantly expanding. Technical characteristics of the equipment improved. Standard Specification updated and modernized. Systems VXI-based technologies highly intelligent, user-friendliness, compatibility with a variety of other hardware systems. The best is to use the VXI systems for conducting scientific tests and research, monitoring and diagnosis of complex technical objects, monitoring the performance of industrial and power facilities;
- When selecting the creation of open standard measuring systems for use in the industry one important issue is the development of standards in the Russian Federation, the presence of Russian producers and their ability to produce a list of all the standard equipment. To date, of the considered standards complete list of components of measuring systems is mastered in the VXI standard. The standard is officially recognized in Russia, has its presentation in the form of GOST, there is Russian manufacturers, the range of devices is quite large (more than 300 types of units, all types of racks, a system-wide interfaces, and several types of modular systems). After appearing in the nomenclature of modules VXI-controller zero slot LXI interface with any VXI-LXI system can be a system or part of it. In fact, VXI and LXI standards complement each other, as the main scope of the VXI standard is to provide a multi-channel and multi-function systems, and for the LXI standard is becoming the main scope of the standard measurement systems. Therefore, as a basic open standards for creating bus-modular systems proposed to apply VXI and LXI standards.
- Choose of open PXI standard is not appropriate, since 90% of the equipment to the National Instruments manufacturing market. No Russian manufacturers produce a full list of the equipment.
- Choose of open standard AXIe impractical, as at present nomenclature of the equipment in the main testing ground on modern element base (VLSI, processors, etc.). For use in the industry this type of equipment will need to develop new modules that entail very high costs.

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# IMPROVING THE DESIGN OF THE PRECISION DRIVE

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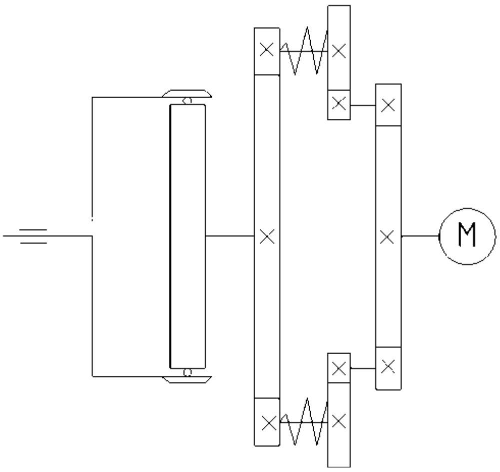
The use of gears in space technology imposes additional requirements to the characteristics of transmission, especially in terms of accuracy, durability (up to 15 years or more) and mass-dimensional arguments due to the impossibility of carrying out maintenance work during prolonged operation of the process. There is also the problem of guidance and positioning of antennas transceivers.

In this article, drive turning reflector design system of mechanical block of the spacecraft, which is located in a stationary orbit. Its purpose is to turn the reflector antenna to a position that eliminates defocusing reflector and feed, arising as a result of thermal deformation of the antenna design. The requirements for this drive, the main of which is a required accuracy of the angular displacement of the output element - less than 1'30", are listed. The achievement of this requirement with minimum dimensions and weight of the drive is the object of the work.

In the article selection kinematic scheme of drive was grounded (pic. 1), which consists of a wave gear and the spur gear reducer (pic. 2). The data to select a drive output stage and ways to achieve the required accuracy at the output stage are presented, the use of the circular configuration of stages according to the type of the planetary gear was justified. [1, 2].




*Pic.1 - Kinematic scheme*

*Pic.2 - General view of the reducer*

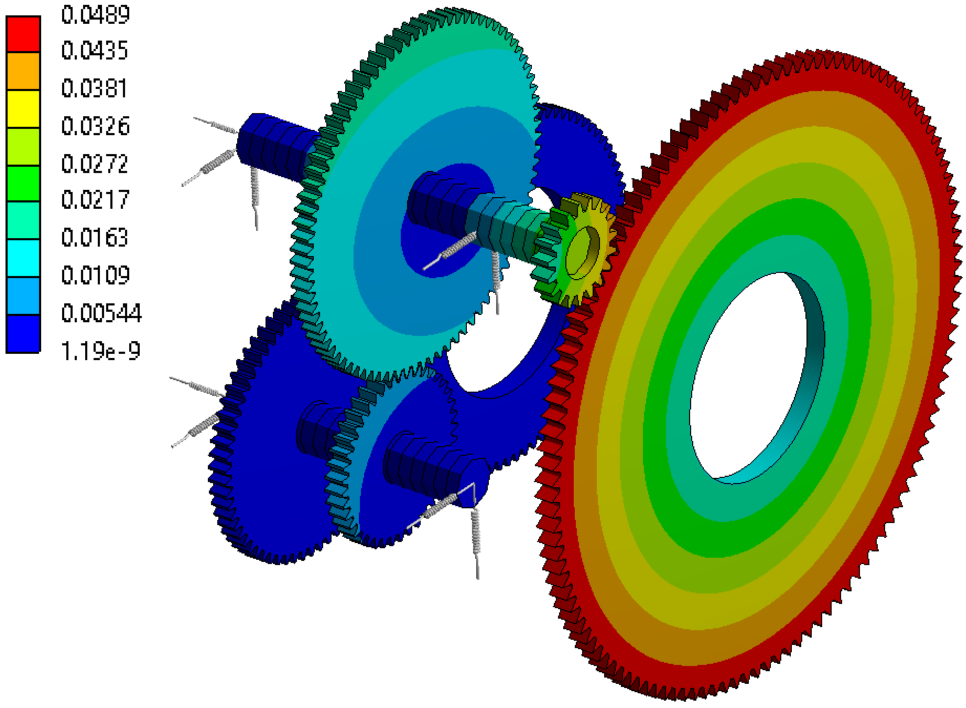
The need for separation of the satellites on three power flow occurred due to the fact that in order to provide the necessary resources in hours of snapping coupling used on the drive, it must have a very large size, and the use of a smaller coupling doesn't provide the required resource, therefore there is the need to use both three couplings.

All types of classical transmission has a gap in gearing, which leads to a backlash and inaccuracy. Applicable devices for gap adjustment lead to the complicated construction, impose restrictions on the range of rotation of the drive output shaft and increase the mass-dimensional characteristics of the drive.

The harmonic gear stage is selected as the output in order to minimize the backlash of the output shaft and the kinematic inaccuracy of the reducer. The combined error in output element is defined as an error of stages divided by the gear ratio of the subsequent stages, and as the harmonic gear has the highest gear ratio, it is preferable to use it as an output stage [3].

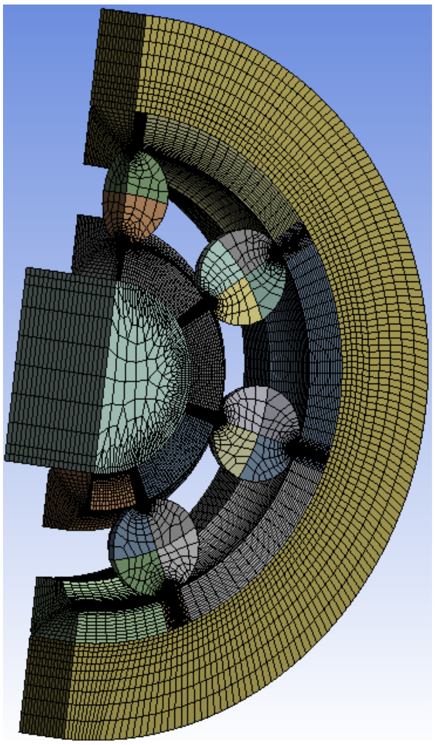
High accuracy (at high accuracy refers to either "precision placement of the gearbox parts" or "uniform load distribution between the satellites") can be achieved on the recommendations Kudryavtsev V. N. [1] with the use of "floating main links" or perfectly accurate manufacturing of gears, or the introduction of elastic linkages (elasticity affects the angular displacement, reduces torsional stiffness). Minimum mass-dimensions characteristics are achieved by rational configuration and arrangement of gear wheels [1, 4].

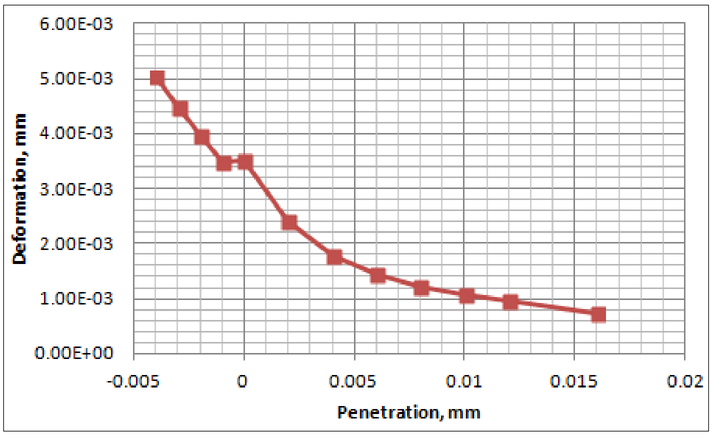
Because the system is statically undeterminable, high precision of manufacturing gears is necessary to guarantee load uniformity between the satellites. And on the basis of that, the correction calculation by increasing the calculated moment by an amount in the longitudinal distribution factor. Longitudinal distribution factor was counted by the use of two calculations: according to the method of calculating by Kudryavtsev [1] and of the built in the finite element ANSYS package simplified drive model [5], for which the elastic drive circuit with a one flow of power was built. In this circuit the bearings are replaced with springs of equivalent stiffness (pic. 3). According to the results are defined as at an applied moment deformed wheels, axles and bearings, and how many arcseconds twisted wheel on the output shaft when rigidly mounted motor shaft. Dependency graph was approximated to find the value of the longitudinal distribution factor. Next, a recalculation of contact and bending stresses was produced, taking into account the irregularity coefficient was founded.




***Pic.3 - Elastic drive circuit, built in finite element package Ansys***

Also for determining the stiffness of supports (needed to calculate longitudinal distribution factor) was modeled bearing segment in the finite element ANSYS package. The results of the contact stresses on the ball were compared with analytical formulas Hertz problem [6], the inaccuracy was insignificant 1.3%. It confirmed the validity of this bearing modeling. Then 1/4 of the bearing has been constructed (pic. 4a), from its calculations the stiffness of a bearing was found, you can also determine on this calculated model the influence of different seats on the amount of deformation of the bearing balls? (pic. 4b).





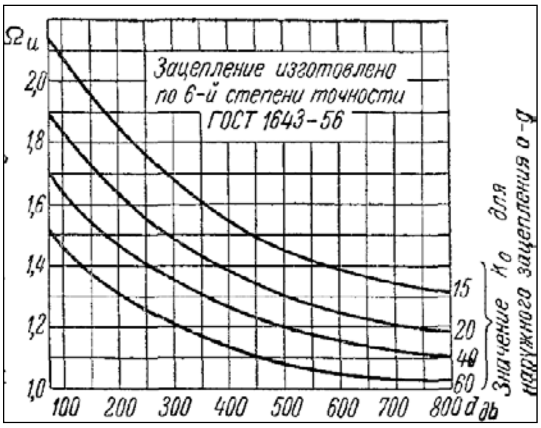

***a.*** ***b.***

***Pic.4 - a) finite element mesh 1/4 of the bearing; b) The dependence of the strain on the gap***

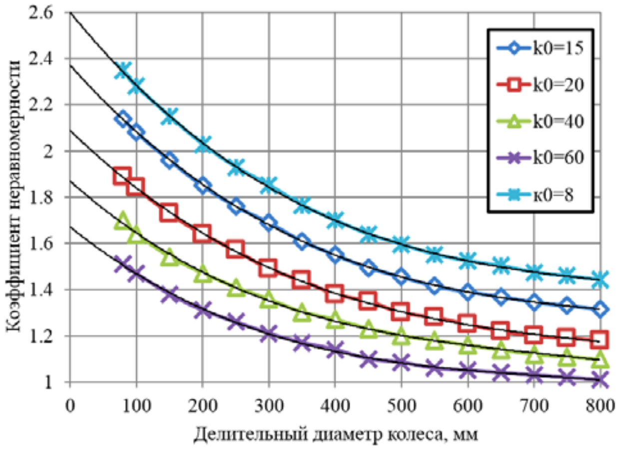
The calculations showed, that the circumferential displacement of the diameter of the tooth top was 49 mm, the wheel of the output shaft is twisted by 331 arcsecond by elastic deformation of the bearings and axles. Dividing this number by the ratio of the wave gear, it obtains the value 1.97 arcseconds on the output element, inaccuracy angular position of the output element with nominal moment will increase on this value.

The next step is to calculate the elastic model with three flows of power, here is already possible to account gaps in gears, axis gear assembly errors.

During the work with the analytical formulas for calculating the longitudinal distribution factor among the satellites it was decided to approximate already known graph (pic. 5a), presented in [1] for the determination of the indicative values $\Omega_k$ and $\Omega_i$ for transmission in the absence of special measures for load balancing among satellites. The value of irregularity coefficient of bending $\Omega_i$ was 2.43, and irregularity coefficient on contact $\Omega_k$ - 1.95, based on the (pic. 5b.).




**a.**




**b.**

***Pic.5 - a) graph to determine indicative quantities Ωk and Ωi for transmission in the absence of special measures for load balancing among the satellites; b) the approximated graph to determine indicative quantities Ωk and Ωi***

After the recalculation of contact and bending stresses with considering of the found irregular coefficients and comparing these values with stress without taking it into account, and also with the working stress, margin of the contact strength was reduced by 28%, by bending - by 10% and 52% for gear and wheel. Further considered exactly how the inaccuracy in the manufacture and erection affect the distribution of forces in the gearing.

In future it is planned to calculation a high-speed and intermediate gear stages, determination the degree of gear precision to provide the required angular position of the output element, the study and consideration of the output element S-shaped profile, the defining the stiffness of the system, the definition of gaps adjustment under the influence of the elastic deformation of gears, the definition of the longitudinal distribution factor between the satellites on the finite element model, while ensuring minimal dimensions and weight of the drive.

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# A NEW TECHNOLOGY OF GEAR MANUFACTURING INVOMILL

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The traditional gear machining methods such as hobbing and shaping pose limitations on manufacturer's ability to produce gears efficiently in small and medium batches. In recent years, new gear machining method (InvoMilling) has been developed. It allows to use standard multitasking machines and standard tools to provide a solution to these limitations. This paper shortly describes this technique and compares its quality and production times with those of traditional gear manufacturing techniques.

The strategies historically utilized for machining of gear teeth have relied on specialized machine tools and cutting tools.

The quality levels and production times associated with these solutions were generally acceptable, but other elements of the commercial situation were not. Specifically the lack of agility to redeploy the machines for various gear types, the long lead times required to acquire tools and machines, and the high cost of the equipment made it impossible for gear producers to implement business plans based on agility in terms of rapid response to customer demands or transition from production of one type of gear to another.

To cut the gear teeth the alternatives of utilize standard machines and standard cutting tools have been developed recently. Two solutions which have been particularly effective in enabling machining centers to productively cut gears are InvoMilling, [1] a gear cutting strategy and tooling developed by Sandvik, and gearMILL, a software solution developed by DMG Mori Pfronten.

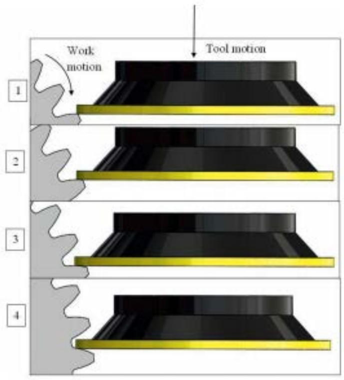


***Fig.1 - InvoMilling Process***

InvoMill utilizes a face cutting tool to interpolate the involute of the gear tooth. The contact between the plane of the tool face and the tooth's involute is described by a line or chord bisecting the plane of the tools face. The tool path is radial, typically from the tip to the root. Therefore the major variables of the gear (module, pressure angle, and helix angle) are determined by the tool path, not the tool itself, a characteristic generally associated with flank or ball endmilling rather than hobbing, gashing, or shaping tools. Unlike end-mills which cut a scallop into the work with each pass, there is no correlation between stepover distance and surface texture for the InvoMill's chord of contact. This enables large step-overs of typically 5 to 15mm for the most common gears in the range of module 3 to 6. In comparison an end-mill would be limited to step-overs of .1 to .3mm. As a result the productivity of InvoMilling can be one to two orders of magnitude greater than end-mill cutting of a tooth.

However the InvoMill shares a constraint with the end-mills representing some difficulties in preparation of a tool path for the CNC program. The traditional CAM solutions are ineffective as the solid models of gear profiles on which they are dependent are generally unavailable. There are multiple reasons; the first one is that many legacy gear designs predate solid modeling in the way that only drawings and gear parameters are available, the second reason concerns the deficiencies in the solid models when they are available. As programming systems for traditional gear generation equipment utilized the parameters of a gear and did not require a solid model, there has been little justification for the effort to accurately model the complexity of the gear tooth, with its subtle complications such as crowning, tip clearance, and root modifications. The gear designers knew that their solid models would not be used for manufacturing and did not push the CAD providers to develop effective modeling tools. This problem was solved by the development of surface based gear solid model generating software gearMILL. This enables programming of gears which have a lack of models, and those which are modeled imperfectly.

InvoMilling process and hobbing process are comparable processes due to the fact that both of them are primarily used for machining of cylindrical gears. To compare the cycle times using two methods, machining times for module 3 and module 6, gears are calculated. The cycle times for high-speed steel hobbing were derived according to industry standard feeds and speeds, recommendations taken from Gear Hobbing, Shaping and Shaving [2].

The cycle times in Figure 2 compare high-speed steel hob double cutting to InvoMilling for module 6 spur gears.

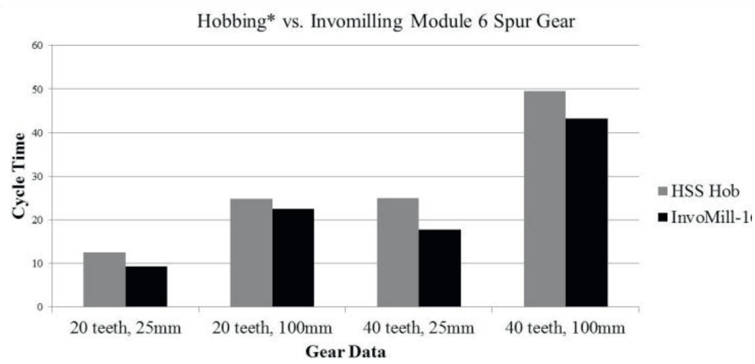


***Fig.2 - Module 6 cycle time comparisons***

Additionally in the above analysis, only the cycle time is considered. If total time is considered – which consists of setup time and machining time, traditional methods have significant limitation due to higher setup times. For small and medium batch production, the setup time becomes relevant. Then InvoMilling will be able to outperform hobbing due to its lower setup time and hence lower overall time. [3]

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УДК 62-1

**PREREQUISITES FOR CREATION OF INTEGRATED CAD\CAM SOFTWARE FOR THE PRODUCTION OF WATER TURBINES, IMPLEMENTED IN THE FORM OF FMS**

**E.A. Spirin**

Russia has considerable energy potential of small rivers - about 60 billion kWh. of less than 0.5% is used today. Now more than 90% of previously constructed SHP owned collective and state farms, written off (mostly hydroelectric capacity of 50-100 kW.) Until 1957, the Soviet Union worked 5615 mini- and micro-hydropower plants with total capacity of 443 MW. Restore abandoned SHP particularly cost-effectively through the use of hydraulic structures preserved. SHP have their own characteristics that distinguish essentially a small power from the big. SHP unit - is not reduced aggregate a large hydroelectric power station, and an independent object, it is characterized by its specific characteristics and requirements.

Thus, small-scale production of hydraulic units for small hydro power plants, must have large-scale production efficiency and flexibility of individual production.

The orthogonal turbine with a ring-shaped blades allows cost-effective implementation of the production units and components for small hydropower plants on the specialized machine-building enterprises, according the customer specified parameters.

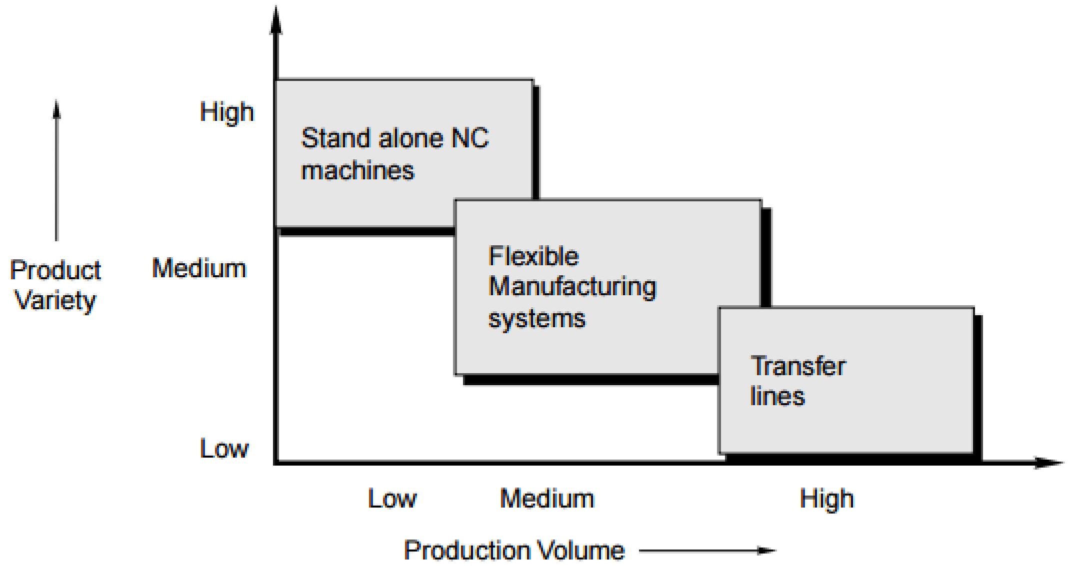


***Fig.1 – Application characteristics of FMS***

A Flexible Manufacturing System (FMS) is a production system consisting of a set of identical and/or complementary numerically controlled machine which are connected through an automated transportation system. Each process in FMS is controlled by a dedicated computer (FMS cell computer).

At the turn of the century FMS did not exist. There was not a big enough need for efficiency because the markets were national and there was no foreign competition. Manufacturers could tell the consumers what to buy. Henry Ford is quoted as saying people can order any color of car as long as it is black. This was the thinking of many big manufacturers of the time. After the Second World War a new era in manufacturing was to come. The discovery of new materials and production techniques increased quality and productivity. The wars end open foreign markets and new competition. Now the market focused on consumer and not the manufacturer. The first FMS was patent in 1965 by Theo

Williamson who made numerically controlled equipment. Examples of numerically controlled equipment are like a CNC lathes or mills which is called varying types of FMS. In the 70ths manufacturers could not stay to date with the ever-growing technological knowledge manufacturers competitors have, so FMS became mainstream in manufacturing. In the 80ths for the first time manufacturers had to take in consideration efficiency, quality, and flexibility to stay in business.

Types of FMS:

- **Sequential** (It manufactures one-piece part batch type and then planning and preparation is carried out for the next piece part batch type to be manufactured)
- **Random** (It manufactures any random mix of piece part types at any one time)
- **Dedicated** (It continually manufactures, for extended periods, the same but limited mix of piece part)
- **Engineered** (It manufactures the same mix of part types throughout its lifetime)
- **Modular** (A modular FMS, with a sophisticated FMS host, enables and FMS user to expand their FMS capabilities in a stepwise fashion into any of the previous four types of FMS)

FMS Layouts:

- **Progressive** (Best for producing a variety of parts)
- **Closed Loop** (Parts can skip stations for flexibility. Used for large part sizes. Best for long process times)
- **Ladder** (Parts can be sent to any machine in any sequence. Parts not limited to particular part families)
- **Open Field** (Most complex FMS layout. Includes several support stations)
- Robot centered type (New form of FMS in which one or more robots are used as the material handling systems)

Development of FMS:

- Selecting operations needed to make the product.
- Putting the operations in a logical order.
- Selecting equipment to make the product.
- Arranging the equipment for efficient use.
- Designing special devices to help build the product.
- Developing ways to control product quality.
- Testing the manufacturing system.

Regardless of the FMS structure, we must create a software that implements information support phases of design, construction and technological preparation of production of hydraulic turbines. The simple design of the turbine allows to implement the basic idea of the planned production: “One Design + One Assembly Process = Multiple Models”.

Model-based systems engineering (MBSE) is a systems engineering methodology which focuses on creating and exploiting domain models as the primary means of information exchange between engineers, rather than on document-based information exchange. In contrast, the classic engineering drawing is fraught with limitations:

- **Interpretation Issues:** A properly executed drawing shouldn't be subject to misinterpretation, but that skill is starting to become something of a lost art. Unclear depictions can be problematic (i.e. which surface did that leader line touch?). More disturbingly, errors can easily escape detection. Sure, most of that can be mitigated with carefully defined GD&T, but that too seems to be a fading skill. PMI improves upon these limitations by clearly associating surfaces and endpoints, and providing validation that such dimensions do indeed make logical sense.

- **Manual Inspection:** Drawings necessitate reinterpretation by humans on the other side of the manufacturing lifecycle. It's another way to introduce error: the botched inspection. PMI sets the stage for automated inspection, accelerating manufacturing processes while simultaneously improving quality.
- **Time is Money:** This is where drawings go for the BRAINS... Simply put, in today's constantly accelerating demand to crank out the engineering in less time, drawings just take too long. Increased market pace demands more efficient processes. An engineer who's spent considerable time defining a model, shouldn't have to spend much longer documenting it. The days of modeling something then throwing it over a fence to lay it out are over. These two aspects of design must occur simultaneously, and this ultimately is only possible with model-based definition.

The biggest change in recent times for the CAD/CAM industry lies with the term "integration". Integration plays a very important role in the future of CAD/CAM products. In the beginning, there were only CAD systems. Engineers used CAD systems to draw pictures of parts. The first CAM systems helped an NC programmer/machinist/manufacturing engineer program from these drawings. This making of drawings, and programming parts from drawings, was (and still is) time consuming and subject to a lot of human error. Someone got the bright idea to eliminate this to-and-from drawing step, and integrated CAD/CAM was born.

**Manufacturing Modeling.** A manufacturing engineer or NC programmer, uses CAD software to:

- Develop a computer model of a part that was defined by a drawing.
- Evaluate and repair the design CAD data to manufacturing tolerances.
- Create new part models from the original design to allow for manufacturability. This would include adding draft angles or developing models of the part for different steps in multi-process manufacturing.
- Design models of fixtures, mold cavities, mold cores, mold bases, and other tooling.

Thus, there are all prerequisites for the creation of software that implements the automation of the stages of design and technology to ensure the production of hydraulic turbines, implemented in the form of FMS.

УДК 629.021

# THE DEVELOPMENT OF INTAKE SYSTEM IN INTERNAL COMBUSTION ENGINE IN STUDENT-CLASS VEHICLE

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SAE formula is better known as Formula Student in Europe. It is a student engineering competition originally organized by the Society of Automotive Engineers (SAE) as a part of Collegiate Design Series (CDS SAE). According to the purpose of competition the team of university students is an engineering company which goals are to developer, build and test a prototype formula-class vehicle for non-professional racing car market. The main task for the teams is to construct a racing car that will be able to pass successfully all the stages of the competition. This team must provide all the design documentation for the project and prove that the applied technical solutions are optimal.

One of the current problems of racing car engineering is a development of combustion engine's intake system which will be based on the provisions of the rules of competition “Formula Student”. Formula Student Combustion Rules intends to limit the engine capacity up to 610 $cm^3$: the appropriate fuel type is petrol. The noise level mustn't exceed the 110 dB threshold as well as the presence of 20 mm air restrictor in the intake system. [4] The developed air intake system must minimize the loss of engine power and fuel consumption.

Air charge system consists of air filter, throttle body, diffusor, plenum and runners. The arrangement example of the air intake system is shown on Figure 1.

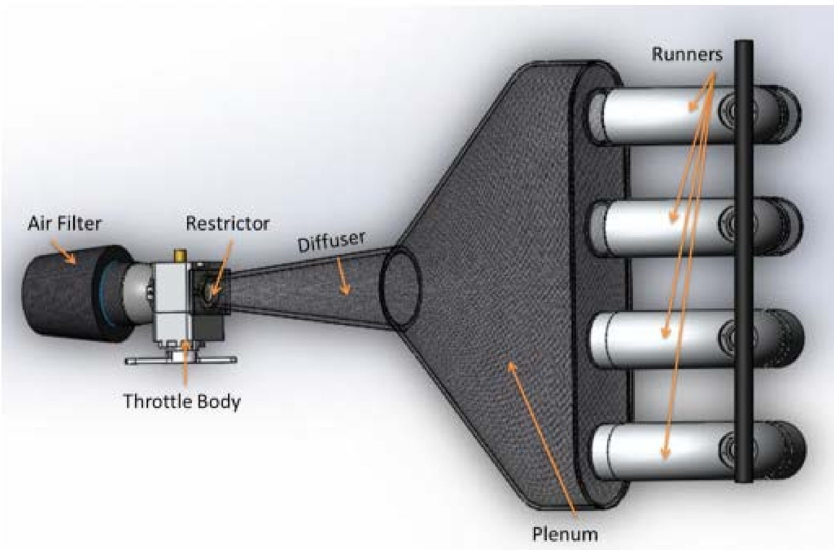


***Fig.1 - Example of the arrangement of air intake system***

Before the air flow completely enters the intake system, it passes through the air filter at the beginning first place. That is done because the air is purified of the particles that could harm the internal components of the engine. Then flow enters to the throttle body which is a throttling device responsible for the regulation of the mass engine air flow by using butterfly valve. [1] After passing through the throttle body the flow enters the converging/diverging nozzle with a 20 mm throat diameter which is dictated by Formula Student rules.

Mechanical losses in the internal combustion system is determined in addition to the restrictor and throttle by the configuration of inlet branches, manifold and air ducts. The optimization of air duct configuration can significantly reduce mechanical losses with help of modern methods of computer modeling.

The engineering methodology is based on Adjoint method and deformation of finite-element mesh method. These methods assume that the definition of connecting dimensions and geometric constraints is associated with layout of the power supply system by using 3D-scanner. (Figure 2).

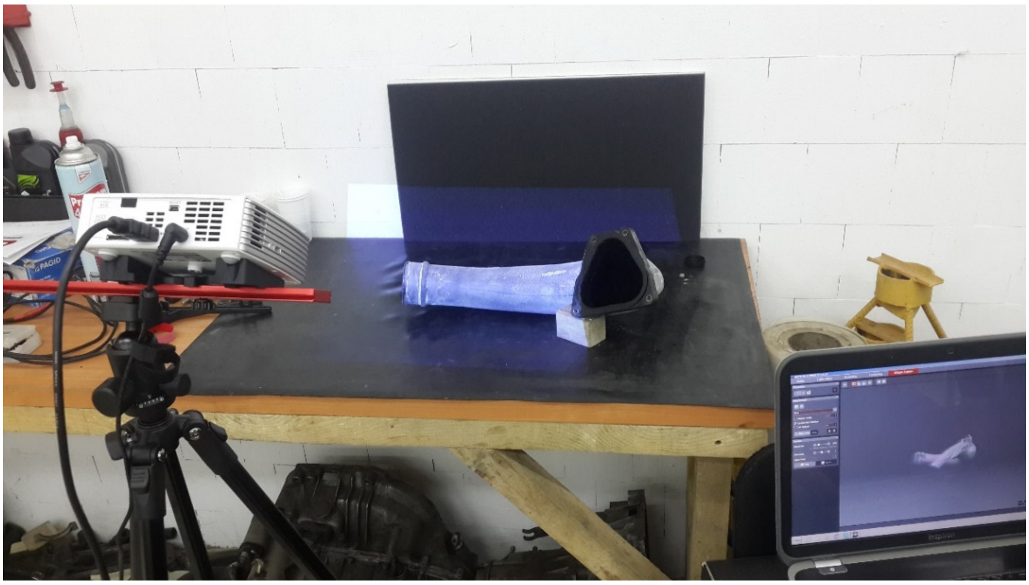

***Fig. 2 - The use of 3D-scanner for determining the connection between dimensions and geometric constraints, associated with the layout of the power supply system***

Synthesis of power supply system's geometry is carried out with the use of modern topological optimization methods for solving the problem of fuel-air mixture. Adjoint Method, the essence of which is to determine the geometric factors affecting a given objective function. The research is provided by multifunctional engineering analysis software “Ansys Workbench”. The selected optimizing criteria is the reduction of non-uniformity of the field of flow rates and the reduction of pressure loss (system resistance). Particular attention is given to the system in the restrictor zone where the formation of a stable vortex structure is highly possible which affects the performance selected system optimality criteria. Figure 3 shows a visualization of the results of numerical modeling for gas flow in the pipe.

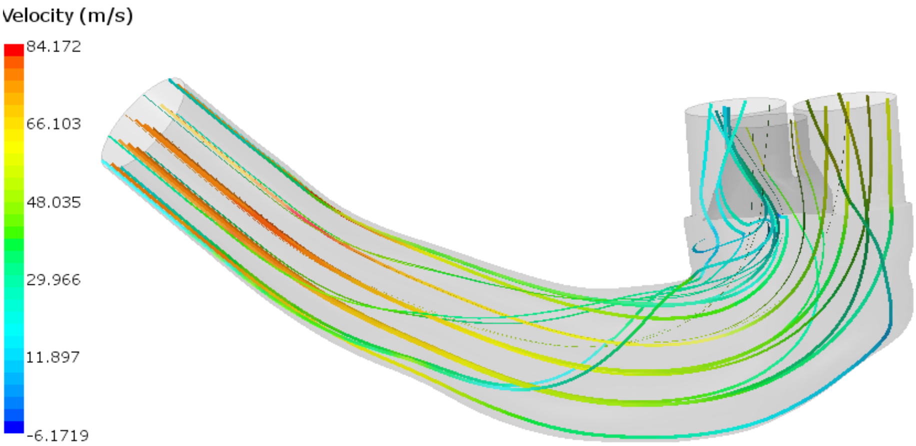


***Fig.3 - The buildup of stable vortex airflow patterns***

The full-speed flow field, presented on Figure 3, demonstrates the heterogeneity of gas flow nature and the presence of “dead zones”. The model obtained by modifying the geometry of construction was able to reduce the resistance by 18.2% compared to the original design (to 345 Pa), and non-uniform flow by 46% to 20.3%. Therefore the amount of air entering the engine cylinders will increase Thereby engine power and fuel consumption losses will be minimized.

The next step the production of a prototype for testing with usage of the purge stand. The sample production should be done with 3D-printing. Then, if it is necessary, contestants must make adjustments (in view of data) of the model in the multifunctional engineering analysis of software “Ansys Workbench”.

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УДК 62-526

**DEVELOPMENT OF MILLING MACHINE USING CAD/CAM**

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During the economic crisis the companies should meet very stringent requirements in terms of operational efficiency. In its turn the production could not be effective without proper equipment. There are not only improvements of technological hardware but software and providing equipment. [1]

The application of information technology in the manufacturing allows significantly improving the product quality reducing the time of manufacture and production of complex products with full quality and the technological developments in the stage of project development. Among the most effective technologies allowing to execute these requirements belong to the so-called CAD/CAM/CAE (computer-aided design, technological preparation of production and engineering analysis). [1]

*Modeling.* In earlier times when the computers had not been developed there had been a representation of using conventional media in designing. Ancient architects used a text abstractly to describe the design process. 2D drawings were later introduced and only expressed abstract visual thinking. The attempts have been continued to identify the nature of different design tools. Last years, digital technology has been developed and matured at an unprecedented rate. This growth has led to a converging phenomenon that erodes the traditional boundaries of computing. Compared with conventional design media it is worth employing computer technology meaningfully to bring significant changes in the process of systems design and maintenance. The conventional approach involves the use of drawings and models as means of representing the basic convention. The type of models used in the design process can either be a physical or digital model. Both types were used as a means of solving complex problems that 2D drawings were unable to handle.3D CAD models are three-dimensional computational representations of objects drawn in the x, y and z axes and illustrated in isometric, perspective or axonometric views. These views are achieved simply by rotating the viewpoint of the object. In general a 3D CAD model of an object provides the following advantages: (a) an object can be drawn once and then can be viewed and plotted from any angle; (b) A 3D CAD object holds mathematical information that can be used in engineering analysis, such as finite-element analysis and computer numerical control technology; and (c) A 3D CAD object can be shaded, rendered and assigned various materials for visualization. 3D CAD models can be generated by the use of various types of CAD software systems. [2]

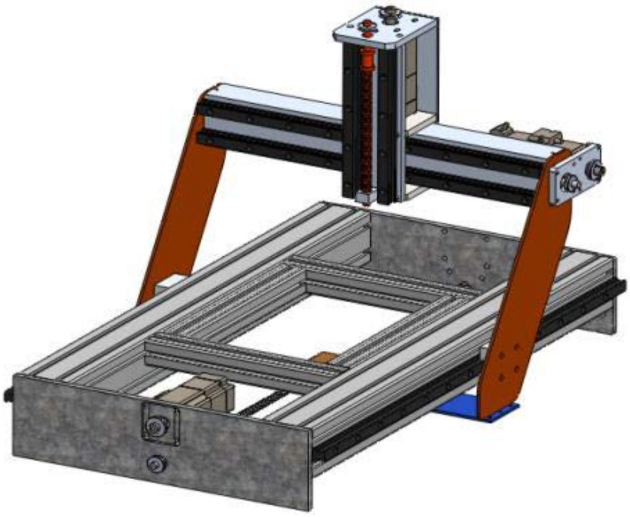

***Fig.1 -CAD model of milling machine***

The finite element method (FEM) is one of the most used methods in engineering. These methods and programs based on it are fundamental usage in CAD. FEA / FEM are indispensable in all engineering analysis where high performance is required. The main purpose of the study is to see a practical application using FEA to improve design of a typical mechanical component. [2]

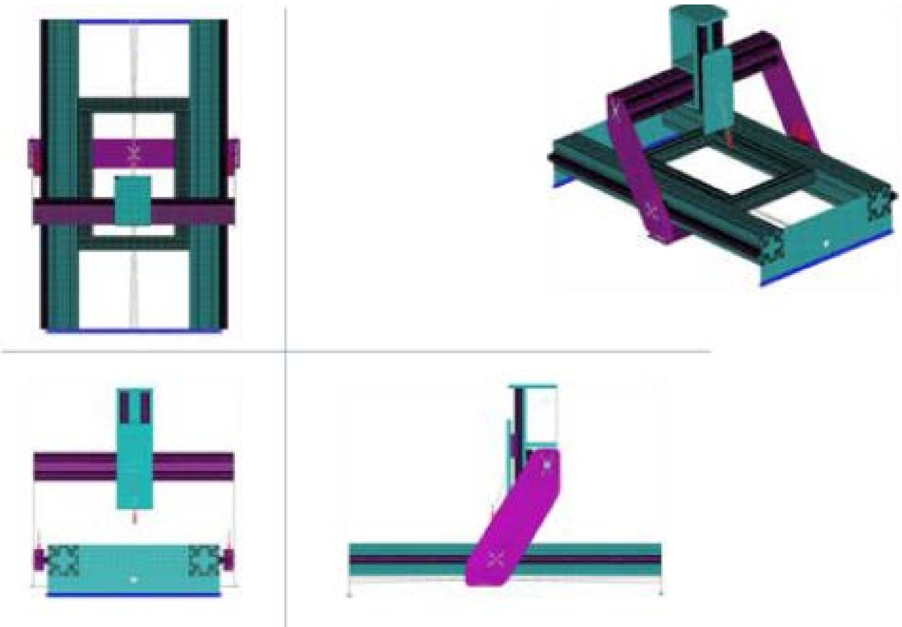

***Fig.2 - Hyper-mesh model of proposed milling machine***

Materials used for milling machine are steel and aluminum. In this fig. the element of machine shown by blue is steel material. Likewise portion of machine shown by purple is Aluminum. In this hyper mesh model there are 463973 total elements and total nodes are 554403. These elements are in 2D as well as in 3D. 2D elements are shaped like triangular and rectangular. Similarly, 3d shapes are in pentahedral and hexahedral shapes. Bluish colored element denotes that part is fixed and constraint. Red colored arrows which are near the gantry denotes loads applied to worktable and red colored arrows which are near spindle denotes moment. [3]

*Defining Boundary Conditions:*

1) To define a problem which results in a unique solution it must specify information on the dependent (flow) variables at the domain boundaries. Specify fluxes of mass, momentum, energy, etc. into the domain.

2) Defining of the boundary conditions involves:

a. Identifying of the location of the boundaries (e.g., inlets, walls, symmetry)

b. Supplying information at the boundaries

c. The data required at a boundary depends upon the boundary condition type and the physical models employed.

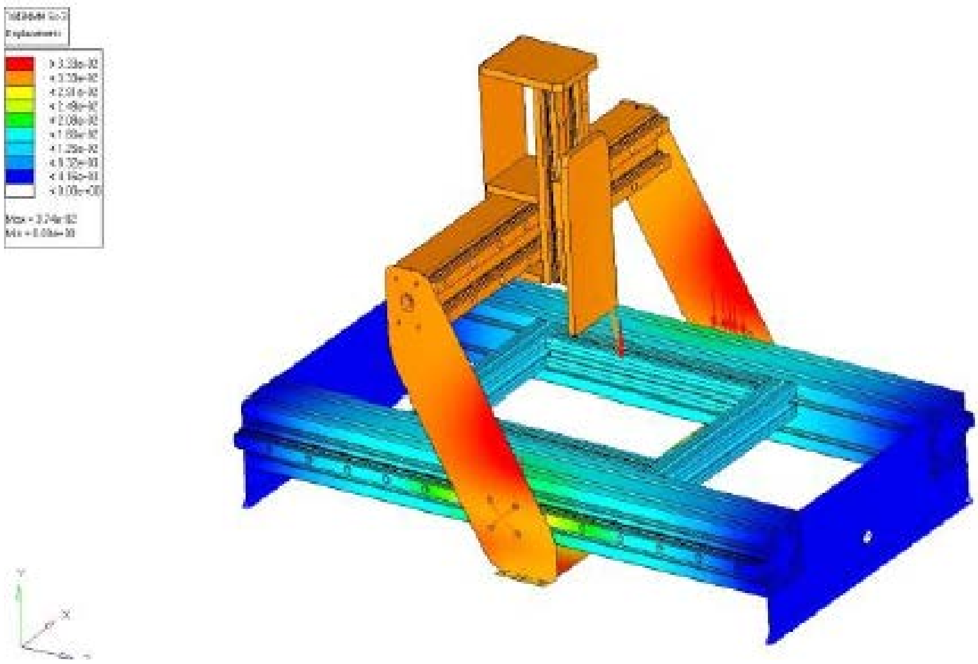

***Fig.3 - Finite elements results***

The results of the stress analysis of a complete milling machine reveal that the maximum stress occurs in the frame where the overall mechanism for the movement is mounted. The maximum stress value is 14 MPa and the allowable stress of the M.S material is 24 MPa. Therefore, we can conclude that the design is safe enough for its application and working. If the stress increases beyond the allowable stress of the material it occurs a failure.

*Part Programming Using CAD/CAM*

A CAD/CAM system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing functions. One of the important tasks performed on a CAD/CAM system is NC part programming. In this method of part programming elements of the procedure are usually done by the part programmer instead of the computer. There are two main tasks of a part programmer in a computer assisted programming:

a) Defining the part geometry

b) Specifying the tool path.

The proposed methodology is used to automate both of these tasks.

Tool path generation using CAD/CAM:

The second task of the NC programmer in computer-assisted part programming is tool path specification. The first step in specifying the tool path is to select the cutting tool for the operation. Most CAD/CAM systems have tool libraries that can be called by the programmer to identify what tools are available in the tool crib. The programmer must decide which of the available tools is most appropriate for the operation under consideration and specify it for the tool path. This permits the tool diameter and other dimensions to be entered automatically for tool offset calculations. If the desired cutting tool is not available in the library, an appropriate tool can be specified by the programmer. It then becomes part of the library for future use.

The next step is tool path definition. There are differences in capabilities of the various CAD/CAM systems, which result in different approaches for generating the tool path. The most basic approach involves the use of the interactive graphics system to enter the motion commands one-by-one, similar to computer-assisted part programming. Individual statements in APT or other part programming language are entered and the CAD/CAM system provides an immediate graphic display of the action resulting from the command, thereby validating the statement.

A more-advanced approach for generating tool path commands is to use one of the automatic software modules available on the CAD/CAM system. These modules have been developed to accomplish a number of common machining cycles for milling, drilling and turning. They are subroutines in the NC programming package that can be called and the required parameters given to execute the machining cycle.

**The result of this work.** We can conclude that the use of CAD/CAM systems will allow not only reducing the development time of the project and the means of production to create test models. All the necessary research for future designs can be made by means of the system and to obtain a sufficiently accurate and objective result. Same thing is with the machining simulation. You can build the handling of complex curved surfaces and a full scan without the use of a test work piece with the help of these systems. Such systems will be successfully applied not only in serial and mass production but in the unit which produces unique and highly sophisticated products. The cost of failure of such productions can exceed several million.

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УДК 67.05

# PREDICTION OF DYNAMIC BEHAVIOR FOR DIFFERENT CONFIGURATIONS IN A DRILLING–MILLING MACHINE BASED ON SUBSTRUCTURING ANALYSIS

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Dynamic models of machine tool structures are essential instruments to evaluate structural performance in cutting operations. In order to fully exploit these models, they must meet three critical requirements such as accuracy, computational efficiency and multi-configuration machine behavior predictability. These virtues are hard to combine in one single model, as the improvement of one feature can easily involve a negative effect in the others. This paper deals with this problem and presents a robust procedure to develop reliable, efficient and versatile dynamic models. First, the machine tool structure is split up in several components. For each component, a finite element model is developed and the necessary corrections are made comparing the numerical results to the experimental data obtained from a modal analysis test. Once suitable numerical definitions of the components are available, substructures are defined, considering some components individually and grouping those with no relative movement. In this process, the connection between components is accurately modeled, checking the resulting substructures experimentally. Secondly, the order of the substructures is reduced using a Component Mode Synthesis approach based on Craig–Bampton method.

## 1. Introduction

Finite element (FE) method has been extensively applied in machine tools modeling due to its ability to simulate dynamic behavior of structures of almost any dimensions and shapes. In spite of being recognized as the most powerful tool to perform structural analyses, the modeling procedure must be done with great care to avoid some inherent problems. Unknown material properties, incorrect geometrical definition and, especially, improper modeling of guides, feed drives and connection elements are common and difficult to detect sources of inaccuracies.

In addition, once inaccurate results have been obtained, checking and correcting a FE model is usually a tedious task. Additionally, FE models of machine tools are generally devised for one specific spatial configuration of the mechanical components and, as the dynamic behavior is changed with changing working positions, a time consuming complete recalculation of natural frequencies and mode shapes is necessary for any change in the relative positions of the components. Besides the previous considerations, it must be taken into account that FE models are composed of a large number of degrees of freedom (dof's). Therefore, a further reduction process is required if low cost analyses are to be performed. Whatever reduction method is used for this purpose, the resulting model, to be considered accurate, must represent correctly the dynamic behavior of the structure with in the frequency range of interest.

A suitable approach to face the mentioned issues is to consider the global structure as an assemblage of substructures. The distinctive feature of this approach is that the substructures are studied separately, independent of the position or characteristics of other machine components, and connected through appropriate joint models. Two different variants of substructuring method such as Receptance Coupling Substructure Analysis (RCSA) and Component Mode Synthesis (CMS) are widely spread in machine tool sector.

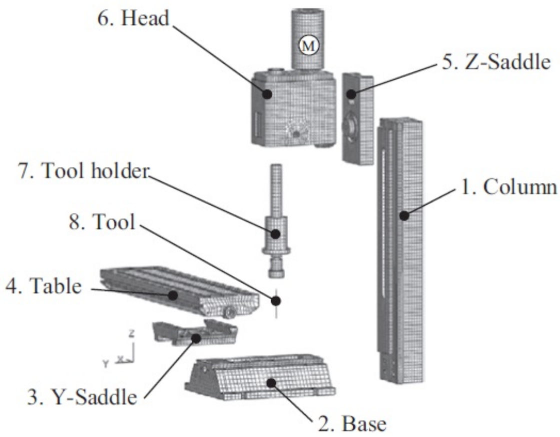
In RCSA, the frequency response functions (FRF's) of individual substructures are used directly to get the response, in FRF form, of the assembly. Pioneering works about RCSA in machine tools were developed by Schmitz et al. Where the tool point response was predicted considering the tool and the holder/spindle as two separate substructures. With the proposed method, they modeled independently various tool geometries and various holders, evaluating the performance of the assembly without having to perform separate sets of measurements for each combination. Later, Park et al. Presented an improved model of the joint dynamics at the assembly and Schmitz et al. Extended the method to three substructures: the spindle-holder base; the extended holder; and the tool. The subsequent progresses in RCSA have been focused on providing solutions related to the previous aspects, i.e., the identification of contact parameters in the connections and the improvement in the modeling of substructures. A common characteristic of the works developed in the receptance coupling field is that they require acquisition of experimental FRF's in any of the connection coordinates. This fact represents a serious practical inconvenience when the link between substructures is done through various connections points, which is the case in the friction guides of the machine studied in this paper, and CMS methods are better suited for these applications. Among CMS techniques, Craig–Bampton methodology is the most commonly used in structural analysis. According to this method, the FE model matrices for each substructure are partitioned into boundary nodes and interior nodes. The boundary set is composed of the dof's of interest, which are kept as physical coordinates. The interior set contains the remaining dof's, which are transformed to a set of truncated modal coordinates. Thus, the Craig–Bampton procedure transforms the FE physical coordinates to a hybrid set of physical coordinates at the boundary an a set of truncated modal coordinates at the interior, allowing the FE models to be reduced in terms of matrices order. These matrices contain stiffness, mass and mode shape information that retain accurate description of the low frequency dynamic behavior.

The application of Craig–Bampton method to evaluate the dynamic performance of a machine tool for different relative positions of substructures requires the use of a large amount of boundary nodes: all the candidate connection nodes between substructures in every possible configuration must be kept as boundaries. This fact limits the model order reduction capability of the method. Moreover, after the assembly process has been completed, all these kept connection dof's are of no practical use and they increase the order of the resulting model unnecessarily. Van Brussel et al. [1] applied such aposition-dependent CMS reduction process obtaining a reduced model size which was 1/23th the size of the full FE model. They recognized the high order of the reduced model and proposed a further reduction step considering the assembled structure as a single component. Law et al. [2] reported reductions of 1/25th and 1/30th in the size of their original FE models, respectively.

This paper presents a procedure to improve the model order reduction capability of Craig–Bampton method when movable substructures are considered. Instead of following the previously applied approach of considering all the sub- structures in one single Craig–Bampton formulation, a sequential two-substructure step procedure has been followed. In this procedure, once two substructures have been assembled, all the connection dof's between them are considered as interior dof's when joining the assembly to the next substructure, and so on until completing the whole assemblage. The benefit of the proposed procedure is that in every step, the unnecessary dof's are extracted from the boundary set and, thus, are no longer kept as physical coordinates. This leads to very low order dynamic models that capture accurately the dynamic behavior of the real machine in the studied configuration. Furthermore, the proposed Craig–Bampton numerical process is combined with experimental substructuring when numerical formulation presents difficulties in implementation. Although the coupling of numerical and experimental models is common in RCSA, it has been rarely applied in other substructuring variants in machine tools, so this paper advances in the application of this research field. The proposed methodology is completed for four machine configurations and numerical natural frequencies, mode shapes and FRF's are extracted from the resulting reduced models. To demonstrate the accuracy of these predictions, they are compared to the results obtained from experimental modal analyses performed in the machine in the same four configurations.

2.1. Theoretical /experimental analysis of components

(Fig. 1) shows the FE models developed for each part of the machine according to the division of components described in (fig. 2).



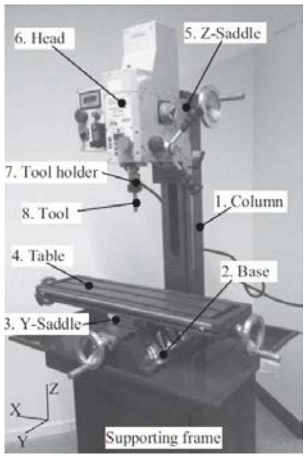




***Fig.1 - FE models of the components*** ***Fig.2 – Drilling-milling machine under study***

Mainly solid brick elements were used in the modeling process. Spring elements were used in the head to simulate the connection with the motor located on top of it and 3D beam elements were used to simulate both the helical and the cylindrical portions of the tool. Cast iron material properties were assigned for all the components except for the tool holder (steel) and the tool (Titanium Nitride coated High-Speed Steel). The accuracy of the FE models was checked and improved through experimental data following model updating processes. Each component was hanged from a steel frame through soft spring store produce free–free boundary conditions and was tested using an instrumented hammer as excitation and two roving triaxial accelerometers as sensors. The response points were carefully selected to fully describe the geometries of the components. The FRF's for the selected degrees of freedom were obtained in the 0–2000 Hz range and the experimental modal analyses were completed extracting modal data. The updating processes were conducted in FEM tools software. These two models were correlated and the comparison showed that modal assurance criterion (MAC) [3] values were good, although the correlated modes presented some differences in natural frequencies. The plot of numerical frequencies against experimental frequencies shows that the frequency pairs lie close to a line of a slope different to unity, which is an indication of an erroneous material property adopted in the FE modeling process. The origin of these frequency discrepancies was attributed to an incorrect value adopted for the elastic modulus, so this material property was taken as the parameter to be modified during the updating process. This decision is based on the great uncertainty of the elastic modulus value in machine components manufactured of gray cast iron, taking values which may vary from E=80 GPa to E=148GPa. This property was modified iteratively, adjusting the numerical frequencies to the experimental ones, obtaining a final value of E=87.11GPa.

The final correlation results show that 8 modes present MAC values higher than 80%, which indicates good correlation, and 2 more modes present values close to or higher than

70%, which indicates acceptable correlation. The maximum frequency difference is about 5%, so the frequency pairing can be considered as very good. The model updating process was repeated for the remaining components in Fig. 2, except for the tool holder and the tool, since their material properties are less uncertain. For these two components, the original FE models were kept. After completing the updating processes, reliable FE models of the components were available, ready to use in further analyses.

2.2. Definition of substructures.

Before proceeding with the reduction stage, a simplification was made in the component definition. Those with no relative motion in the positions which will be studied later in Section 4 were grouped. The base and column were assembled in one single substructure and the same was done with the Z-saddle, head, tool holder and tool. The column and the base are linked through 4 M 12 bolts tightened firmly at 165 m N torque, so the connection is highly rigid. A simplified procedure was adopted to model this union, based on the so called coupled bolt model. According to this procedure, the threaded and unthreaded parts were modeled with linear 3D beam elements along the axis of the holes and the resulting nodes were coupled rigidly to the radially adjacent nodes of the holes of the two components. Due to the high rigidity of the connection, contact interfaces between the base and the column were modeled by rigid regions between the nodes of the contact areas. The comparison reveals that the first 8 paired modes (up to 1000 Hz approximately) present MAC values close to or greater than 80% with small frequency differences, demonstrating that the bolted connection has been simulated correctly. To group the Z-saddle, head, tool holder and tool in a single substructure, the major problem was encountered when linking the Z-saddle and the head. Their connection presents a considerable contact area, but unlike in the previous case, rigid regions between nodes of the surfaces would lead to an incorrect representation because the link cannot be considered as totally rigid. A procedure based on linking the contact nodes through elastic spring elements was adopted, modifying the elastic constants until a correct representation was obtained. The links between the head and tool holder and the tool holder and tool did not present practical problems. They behave as rigid joints and so they were modeled using high stiffness spring elements between adjacent nodes. After completing the grouping of the components. Therefore, the subsequent study will be performed considering 4 substructures: A, B, C and D.

3. Conclusions

This paper presents a robust substructuring procedure to develop a reliable reduced dynamic model for machine tools suitable for different geometrical configurations, combining several modeling procedures successfully.

Craig–Bampton method was selected to reduce the order of substructures and to place them in the desired spatial configurations. Traditionally, such position dependent analyses have shown the disadvantage of keeping all the candidate connection dof's in the final model, diminishing the model order reduction capability of the method.

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