Investigation of the processes occurring during the operation of the torque converter hub in the Belarusian Autoworks gearbox during CAE modeling

Abstract. The main objective of the study is to identify and eliminate the causes of breakdowns in the torque converter hubs of mining dump trucks Belarusian Autoworks.

The relevance of the work carried out: during the operation of dump trucks based on Belarusian Autoworks vehicles, in open pit conditions, according to enterprises operating such equipment, in the period from 2019 to 2021, 75% of the failures and breakdowns of equipment occurred due to the fact that the hub of the torque converter impeller is intensively loaded a part, which during its operation is affected not only by mechanical loads, but also by temperature and others leading to the failure of the specified unit in 85% of cases. For example, hydrodynamic forces that arise during the period of immersion of gear teeth in an oil bath, and so on. Therefore, it is proposed to conduct a comprehensive study of the processes occurring with the wheel hub and identify the main loaded places. Taking into account the analysis carried out, it is possible to produce a batch of wheel hubs with updated parameters and conduct their full-scale tests.

The novelty of the work carried out lies in the analysis of the operating conditions of the hub, which revealed a high boundary pressure that occurs at the point of transition from the air to the oil bath.

The object of research is the study of the processes that occur during the operation of the torque converter hub, which affect the structure and occur in the hub itself.

Research objectives:

- learn the ways and methods of conducting CAE analysis;
- analyze the design parameters of the installation that occur in the torque converter bushing.

Research methods: When performing the dissertation work, methods of physical and mathematical modeling and system analysis of information, laboratory, bench and operational tests using computer and high-precision measuring equipment were used.

Keywords: CAE modeling, torque converter hub, hydromechanical transmission box.

Introduction

Engineering analysis of the transformer hub is an urgent engineering task in the conditions of the Maker LLP enterprise. Under the conditions of the enterprise, manufacturing is carried out from SKD parts supplied from the territory of the Republic of Belarus and repair and restoration of worn components and parts. During the operation of the enterprise, for the period from 2017 to 2019, at the enterprise of 9 BelAZ-75135 dump trucks with a carrying capacity of 110 tons, as well as 4 BelAZ-7513 dump trucks with a carrying capacity of 130 tons, the main most worn parts were torque converters in hydromechanical transmission Fig.1.).

Fig.1. - Hydromechanical gearbox of BelAZ dump truck

It should be noted that the equipment, and most importantly for this work, the torque converter units, were designed to work on specially equipped roads, with a maximum length of 6-8 km at a rise of 5-8%, with a turnaround time of at least 170,000 km. However, the technique didn’t work in some cases even 50,000 km.

In the hydromechanical transmission, a complex, single-stage, lockable, four-wheel torque converter is used. At high loads, it increases the torque transmitted from the engine, and at low loads it transmits it without change, i.e. operates in hydraulic mode.

The most worn part of a hydromechanical gearbox is the torque converter hub. In all cars that came for repairs in the period from 2019 to 2021, the hub (Fig.2.) was, in 4 cases, broken into two or more parts, in other cases it was worn out to over critical values.

The torque converter hub is attached to the crankcase and is a distributor of oil supplied to engage the friction clutches of the gearbox and block the torque converter, as well as to the torque converter cavity and to the lubrication line for lubricating the friction clutch disks and bearings.

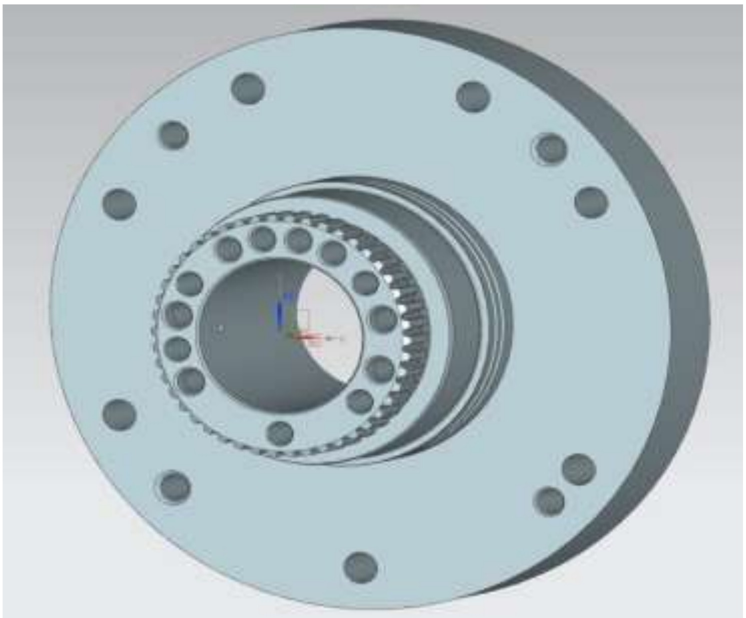


Fig. 2. - Hub of the torque converter

During the analysis of the causes of breakdowns of the torque converter hub, there are: wear and destruction of the working surfaces of the wedge-shaped grooves, support hub and DOA rollers; destruction of the blade system, filling with wear products of the working cavity and channels for pumping the working fluid.

Failure leads either to the exclusion of the possibility of timely locking of the reactor wheels, or to jamming of the DOA rollers and complete blocking of the reactor wheels.

It is possible to diagnose the loss of the ability to jam the DOA of the second reactor in the dump truck acceleration mode, which significantly increases the acceleration time to a given speed, and reduces the distance traveled during this time. If the DOA of any reactor turns out to be not wedged during the acceleration of the dump truck at high values of the so-called gear ratio, then this malfunction can be detected by excessively rapid heating of the working fluid at the outlet of the gas turbine engine, since its efficiency will begin to decrease sharply.

To study the above problem, it is necessary to analyze the main factors affecting the torque converter bushing, as well as find out how these effects affect the ability to carry out their direct technical functions. To carry out such an analysis, it is possible to conduct full-scale tests, which, however, require large labor and economic costs and take long time intervals. And the second method of analysis, using CAE technology, and specifically the ANSYS software package [1].

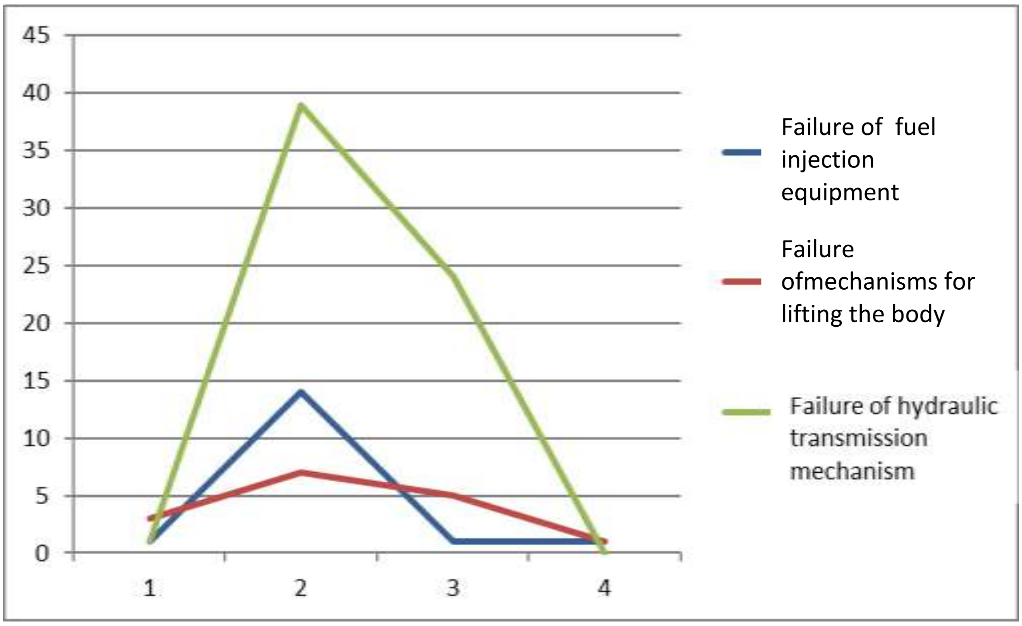
1 Analysis of the operation of the design of the torque converter hub

During the analysis of the design of the torque converter hub, data were obtained on defective machines, the reasons for their failure, and the main defects were studied.

So, for example, from January 2019 to December 2021, 37 Belarusian Autoworks cars were out of action, the main reason for failure in 30 cars is a breakdown of the torque converter hub or a complete failure of the torque converter. So, compared with machines manufactured at enterprises in other countries, the number of exits for a similar reason is presented in table 1.

Table 1 - Statistical data on the failure of cars of the Belarusian Autoworks brand manufactured in the territory of the Republic of Kazakhstan and the Republic of Belarus

Car model	Place of manufacture	Year made	The number of cars in total working in the quarries of the region	Causes of failure of equipment for the period from 2017-2019			Total number of failures
				Fuel equipment failure	Failure of body lifting mechanisms	Failure of the hydraulic transmission mechanism	
BELAZ 7555	Republic of Belarus. City of Zhodino; Belarusian Automobile Plant	2017	12	1	3	1	5
BELAZ 7555	The Republic of Kazakhstan. Karaganda city, KLMZ plant	2017	15	14	7	39	60
BELAZ 7557	The Republic of Kazakhstan. Karaganda city, KLMZ plant	2018	5	1	5	24	30
BELAZ 7513	Republic of Belarus. City of Zhodino; Belarusian Automobile Plant	2018	3	1	1	0	2



Pic. 3. - The main reason for the failure of Belarusian Autoworks cars

As can be seen from the presented statistical data, the main reason for the failure of cars is the failure of an automatic transmission, and a similar problem is observed only in cars manufactured under license at the KLMZ plant in the Republic of Belarus.

Also, all defective products were studied (Fig. 4-6.).

Fig. 4. - Defective torque converter hub

Fig. 5. - Torque converter hub assembly

Fig. 6. - Torque converter hub of Belarusian Autoworks car with signs of wear

The presented materials show that the main place for the development of an automatic transmission breakdown is the torque converter shaft hub.

Thus, in order to work out and determine the main causes of wear, it is necessary to carry out mathematical modeling.

2 Analysis of the mathematical model of the torque converter design

The 3D model of the torque converter impeller hub is divided into elements that will correspond to all geometric characteristics. For these elements, the physical and mechanical characteristics of the materials that make up the hubs are set. After that, boundary conditions and external influence on the model are set. To set such a module of restrictions, it is necessary to enter into the software package a number of mathematical dependencies that describe the relationship of physical processes occurring during the operation of the hub. The second most important event is the search for input parameters that will allow you to determine and set the initial and final conditions of work. Similar work should be carried out for each element where a different computational grid is used [2].

During the work on the model, it was confirmed that all the main dimensions of the hub were taken on the basis of the design calculation of the entire assembly.

After determining all the boundary conditions, it is necessary to set the parameters of the solver. For example, if you set the iteration parameter to 40, the solutions will match field tests 60% of the time. This parameter allows you to assess the reliability of the studies. For the first preliminary calculation, this parameter can be set much less, since the analysis is carried out on a structure that is in operation and has a margin of safety and durability, confirmed by full-scale tests and work in real conditions [3].

To carry out the design analysis procedure, it is necessary to determine with what maximum pressure the torque converter impeller hub supplies oil through the oil lines to the torque converter overrunning wheel. Determining the pressure, as well as the angular velocity and the forces developed at the same time, will be a test of the operability of the structure as a whole, it will allow you to track changes in these parameters by changing both the manufacturing technology of the hub and making changes to the design of the part itself.

Let us give a brief algorithm for creating a model in the Ansys system by transferring the main geometry from the NX software package (Fig. 7.).

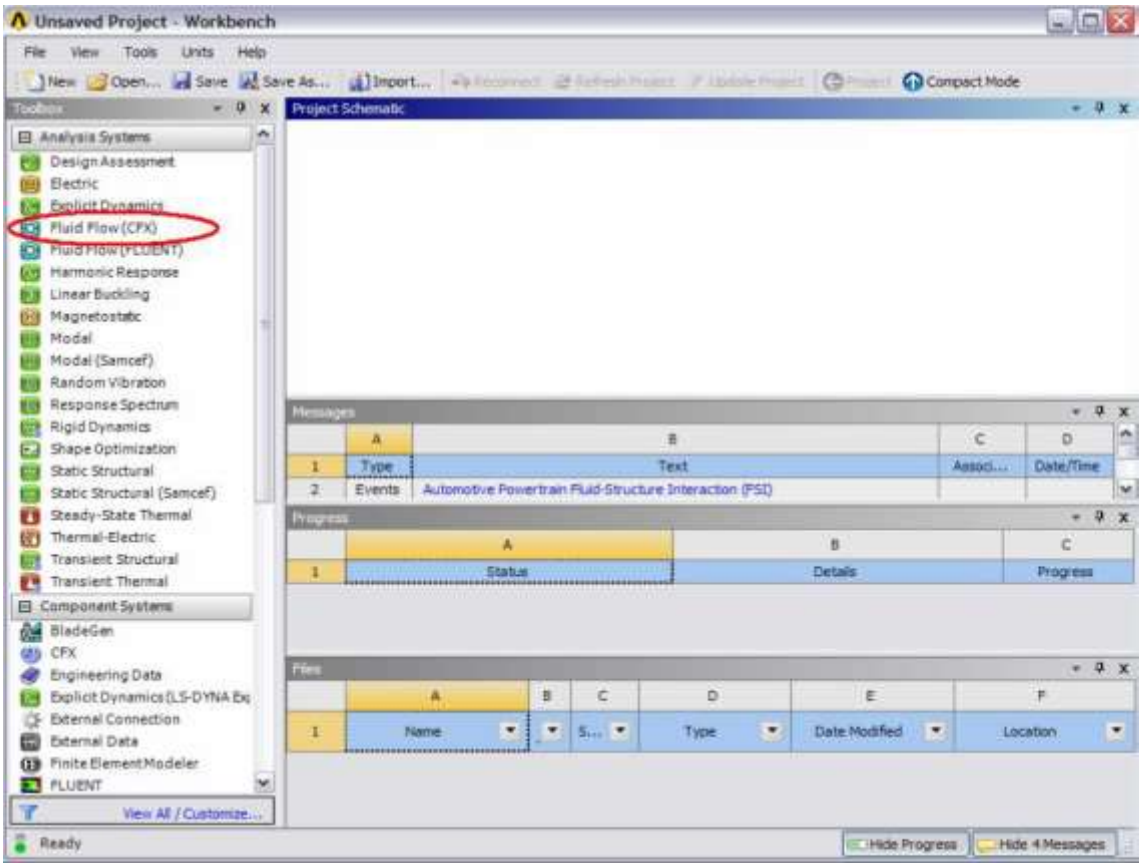


Fig. 7. - Dialog box for creating a new study of basic design parameters

During the transfer of the finished geometry of the hub, it is necessary to dwell on a number of basic requirements, without which the studies will have significant errors. The first significant feature of working in the Ansys software package is the use of units of measurement in feet and inches by default (Fig.8.). And the second feature of the portable model is the variable diameter of the oil lines in the hub housing.

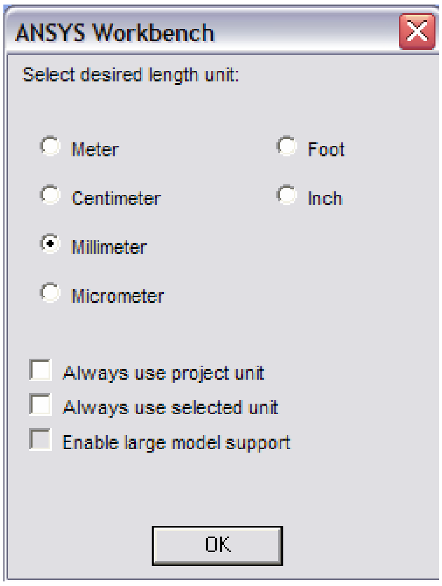


Fig. 8. - Dialog box for selecting the project calculation system

Details of Bend4	
Bend	Bend4
Base Plane	XYPlane
Operation	Add Frozen
Origin Definition	Coordinates
FD3, Origin X Coordinate	0 mm
FD4, Origin Y Coordinate	0 mm
FD5, Origin Z Coordinate	10,75 mm
Axis Definition	Components
FD6, Axis X Component	0
FD7, Axis Y Component	0
FD8, Axis Z Component	1
Base Definition	Components
FD9, Base X Component	0
FD10, Base Y Component	1
FD11, Base Z Component	0
FD12, Angle (>0)	360 °
FD15, Radius (>0)	89,2 mm
FD13, Base Length (>0)	20 mm
FD14, Base Width (>0)	16 mm
As Thin/Surface?	No

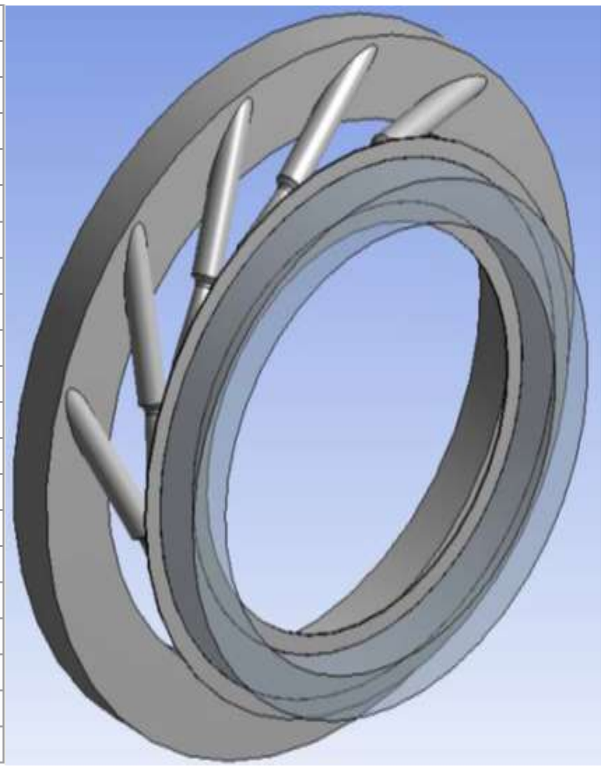


Fig. 9. - General geometrical parameters of oil pipelines in the body of the hub of the torque converter impeller

To conduct a study of the main parameters of the structure, as mentioned above, it is necessary to split the entire geometry into a grid of control volumes. Taking into account the fact that all the main elements of the structure must be broken with the most efficient step [4].

All operations for dividing into control grids are typical sequences of actions. For example, to create a mesh on the rear working surface of the torque converter impeller hub, it is necessary to create the boundary faces of this surface and set their sequence (Fig.10.).

For the convenience of selecting the desired surfaces, it is necessary to use the possibility of partially canceling the display of the structure, since the choice of incorrect parameters often entails an incorrect calculation.

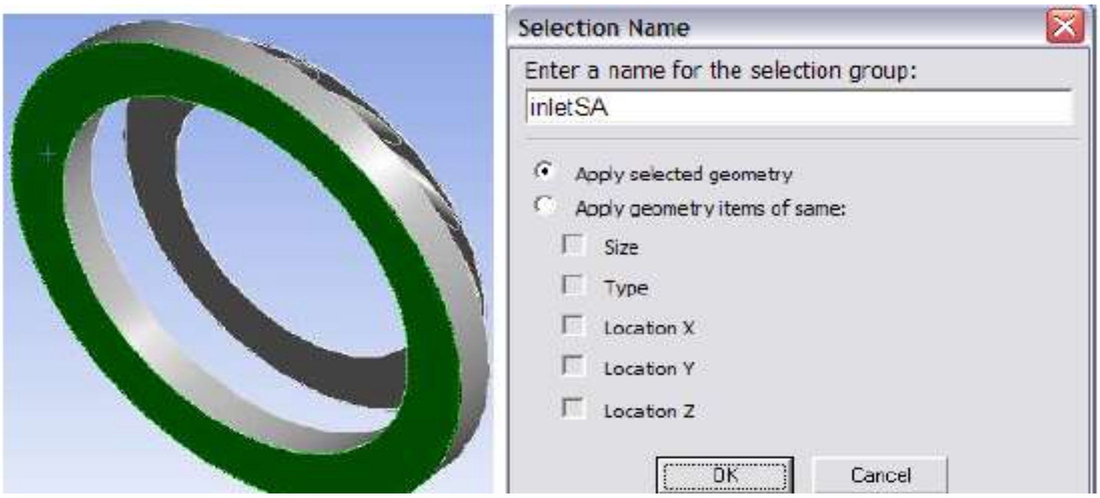


Fig. 10. - Selection of initial and boundary surfaces

Since the finite element method is based on the method of mathematical matrices [5]. That is, the entire surface of the body that is being considered is divided into a large number of polygons, each of which can be described by the equations of physics, mathematics in partial derivatives, then it is necessary to set the boundary conditions and actions of mathematical operators (Fig. 11.).

Inflation	
Use Automatic Inflation	Program Controlled
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No

Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (18,0 °)
Min Size	Default (9,3225e-005 m)
Max Face Size	Default (9,3225e-003 m)
Max Size	Default (1,8645e-002 m)
Growth Rate	Default (1,20)
Minimum Edge Length	1,3263e-003 m

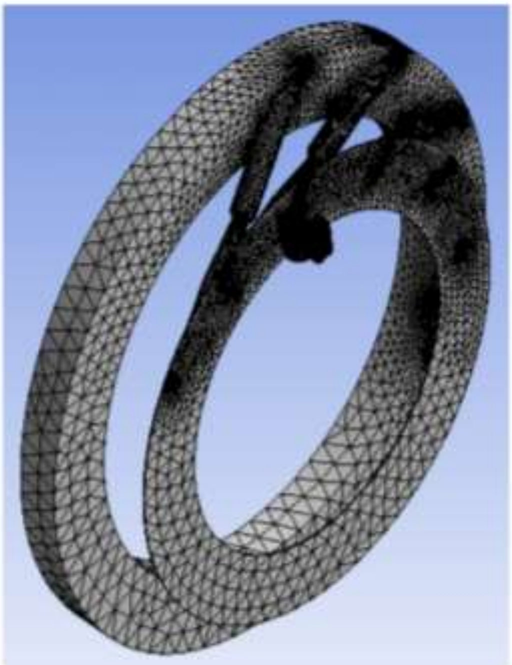


Fig. 11. - Setting basic grid parameters

After carrying out similar procedures with all elements of the torque converter impeller hub, it is necessary to conduct a visual analysis of the structure for uniformity of filling the entire surface of the structure with mesh elements (Fig. 12.).

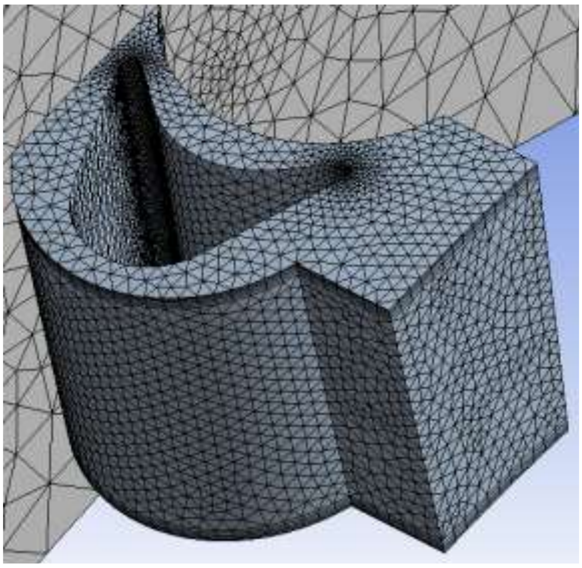


Fig. 12. - Visual analysis of the uniformity of filling the surface of the structure with a mesh

To conduct a full-fledged study of the influence of the main structural parts and methods of manufacturing a hub, it is necessary to simulate the process of operation of this product.

To conduct such a study, we will create a calculation model in which we will lay down the main boundary conditions for the operation of the torque converter impeller hub (Table 2) and configure the program solver module.

Table 2 - Boundary conditions for torque converter hub parameters

Parameter designation	Units of measurement of the parameter	Numeric values
Maximum developed power at the hub	kW	50
Maximum angular speed of rotation of the hub	s^{-1}	3394
Oil flow through hub oil lines	kg/s	97,8
Oil pressure at the outlet of the oil pipelines of the hub	kPa	300
Oil pressure at the inlet to the oil pipelines of the hub	kPa	200

Based on the description of the design of the entire unit, it should be noted that in the cavity where the hub of the impeller of the torque converter is located, there is a small amount of air and atomized oil, therefore, it is necessary to take into account the influence of these conditions, for this we will make changes to the environmental conditions subprocessor (Fig.13,14).

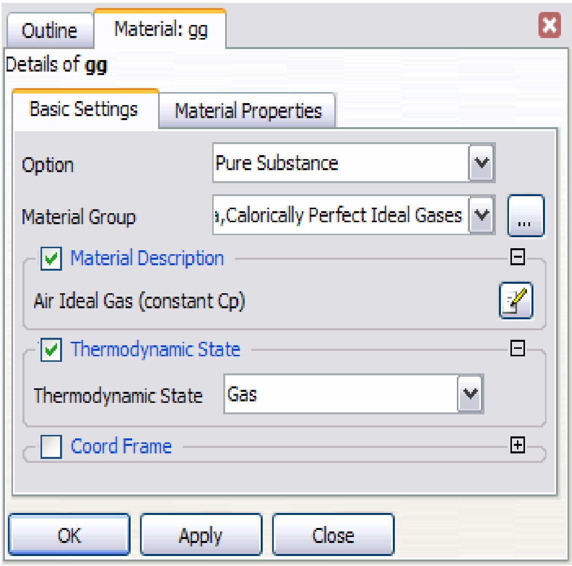


Fig. 13. - Menu for making changes to the environment parameters during the experiment

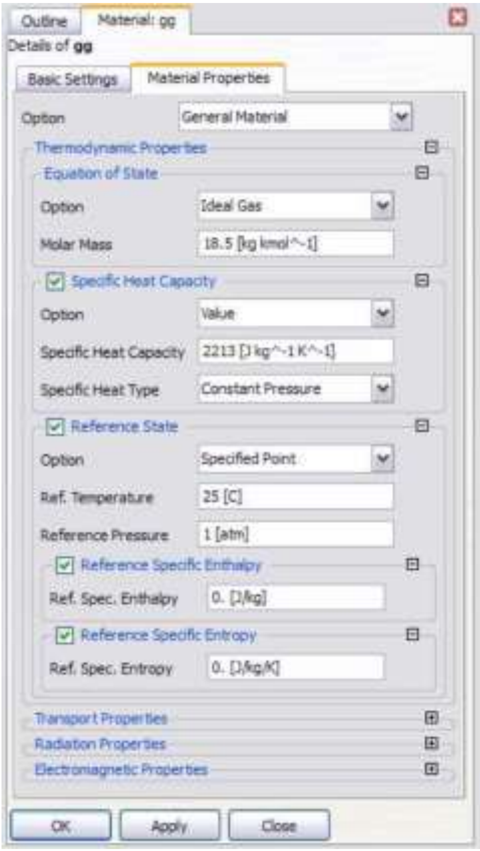


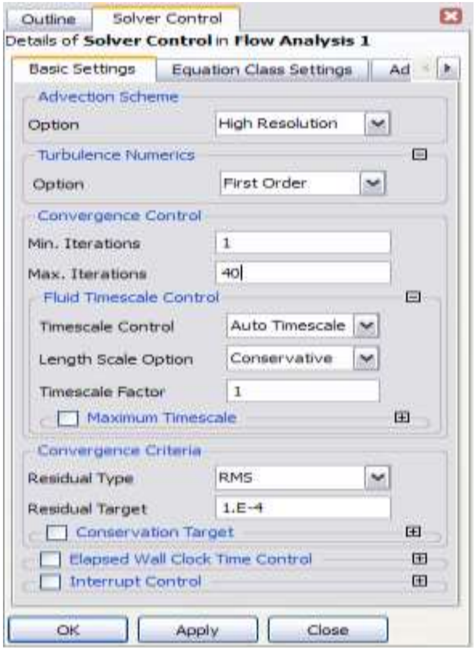
Fig. 14. - Changes made to the environment parameters

The next stage in the creation of the calculation model is the process of determining the zone of action of the given conditions. That is, the approximate dimensions of the cavity where the impeller hub is installed are set, the temperature at the beginning and at the end of the cycle, ambient pressure, humidity, contact boundaries of various media are set. Conditions are set for the maximum and minimum flow rate of the working fluid through the oil pipelines, temperatures in different sections.

Next, a calculation zone is created in which the specified conditions will be created (Fig. 15.).

Fig. 15. - The main parameters of the environment during the experiment

After determining all the boundary conditions, it is necessary to set the parameters of the solver. For example, if you set the iteration parameter to 40, the solutions will correspond to field tests in 60% of cases (Fig. 16.). The indicated parameter - iteration, allows us to evaluate the reliability of the studies, however, for the first preliminary calculation, this parameter can be set much less, since the analysis is carried out on a structure that is in operation and has a margin of safety and durability confirmed by full-scale tests and work in real conditions.



Pic. 16. - The result of the boundary conditions and specifying the degree of accuracy of the solver

As mentioned earlier, in order to find and develop all possible design parameters, the most complete 3D model of the torque converter hub design is required. As it became known, in the course of working on the model, all the main dimensions of the hub were designed on the basis of the design calculation of the entire assembly (Fig. 17.). The torque converter model was made in the NX software package [5].

Pic. 17. - Model of the torque converter of the car Belarusian Autoworks

After building a complete model of the analyzed node, simulations of the node operation process were carried out. However, due to the high complexity of conducting this kind of research, the moments of interaction between the turbine wheel structure and the hydraulic fluid were analyzed (Fig. 18.).

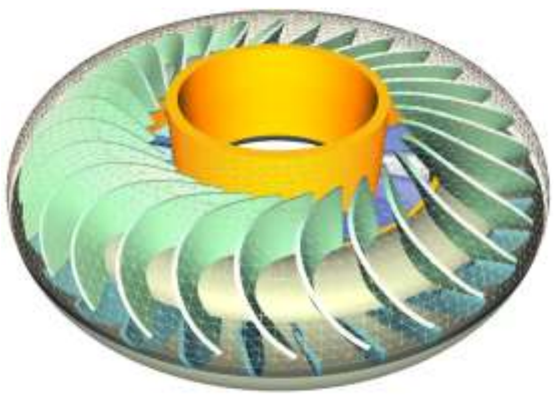


Fig. 18. - Model of a working hydraulic transformer of the Belarusian Autoworks car made in Ansys

Also, to ensure the accuracy of the unit, all the main units were made, the influence of which on the operation of the torque converter is taken into account in the work (Fig. 19.).

Also, during the construction of the model, factors such as the influence of the ambient temperature during the operation of the mechanism, the operating time, and the type of working fluid were taken into account.

It is worth noting the fact that due to the imposition of certain conditions on the calculation in the ANSYS system [6], namely the increase in the time of the calculations, for example, when using the full-fledged model shown in picture 7, the calculation time increased to 2 months and 7 days of computer time. Such calculation terms are not acceptable for real production. Thus, some of the mating parts were replaced by boundary conditions, taking into account the parameters below (Table 3).

Table 3 - Main geometric parameters of the hub

Parameter designation	Value
The maximum diameter of the hub, mm	180,23
Maximum diameter of the oil channel, mm	13,1
Minimum diameter of the oil channel, mm	10,98
Degree of partiality	0,42
Number of oil channels	8
Hub lattice pitch, mm	9,78
Number of rotor blades	67

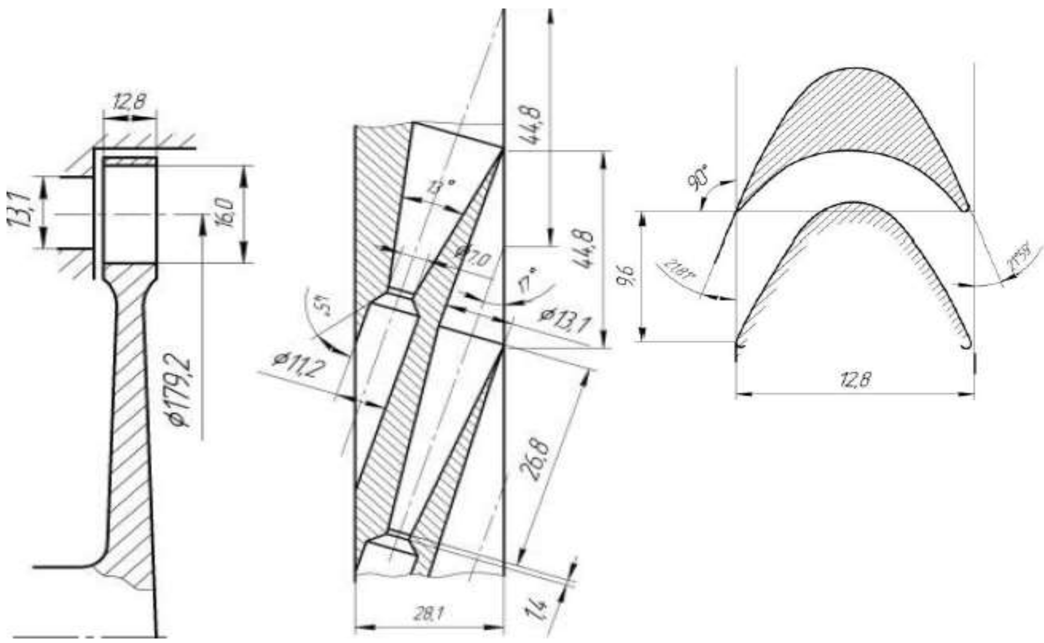


Fig. 19. - Main parameters and geometric dimensions of the most loaded parts of the torque converter impeller hub

Thus, in order to determine some parameters of the boundary conditions, it is necessary to conduct separate studies, for example, calculations were made for the blade blade of the turbine wheel of the torque converter, since when studying full-scale samples, at the manufacturer's plant, traces of cavitation resolution and the appearance of a network of cracks. However, the operating conditions of the unit as a whole cannot be the cause of such a defect; also, when studying the design documentation at the manufacturer, data were obtained that the replacement of the recommended structural material was not carried out. Thus, the study of the phenomena occurring in the process is also necessary (Fig. 20.).

Fig. 20. - Volumetric model of a turbine wheel blade

Conclusion

According to the results of the calculation carried out in the program, taking into account all possible related factors, a picture of the stress distribution in the body of the blade was obtained (Fig. 21.).

The marked impact zones are in excellent agreement with the parameters collected during field observations [6].

On the mathematical model, the zone of maximum loads is visible at the root of the turbine wheel blade, and a regularity was found in the analysis of factory drawings. In turbine wheels assembled by welding the turbine wheel blades with the wheel itself and the hub and the hub assembled by milling with a CNC machine, in 85% of cases the destruction of the impeller hub began in the welding zones.

Confirmation of the received data can be seen in Fig. 21.

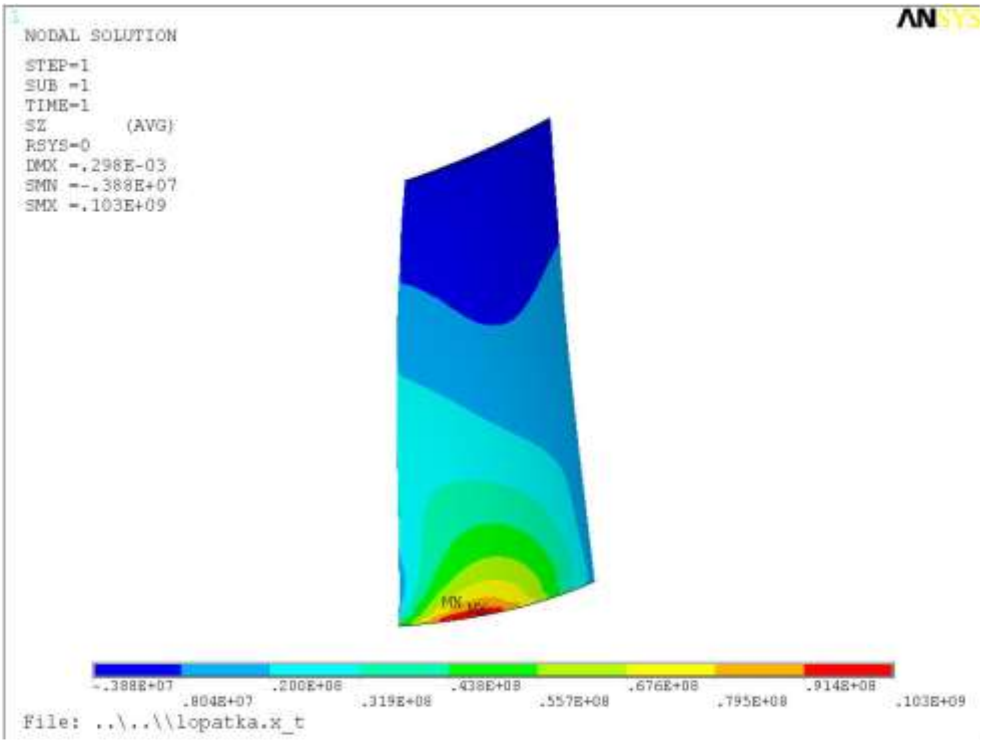


Fig. 21. - Voltage in the turbine wheel blade when the torque converter hub reaches operating speed

Another factor necessary to study the operation of the torque converter hub is to study the process of pumping fluid in the cavities of the hub itself and the effect of the outgoing fluid velocity on the development of cracks in the hub itself. So, compared with the design made on a CNC machine, the dimensions, quantity and quality of these holes are very different from those in the torque converter hubs made at the KLMZ plant.

To study the influence of these parameters, the hub model was analyzed at speeds and operating modes of the corresponding performance characteristic.

So, it turned out that the quality of the holes obtained at the KLMZ plant differs from those obtained on a solid workpiece (Fig. 22.).

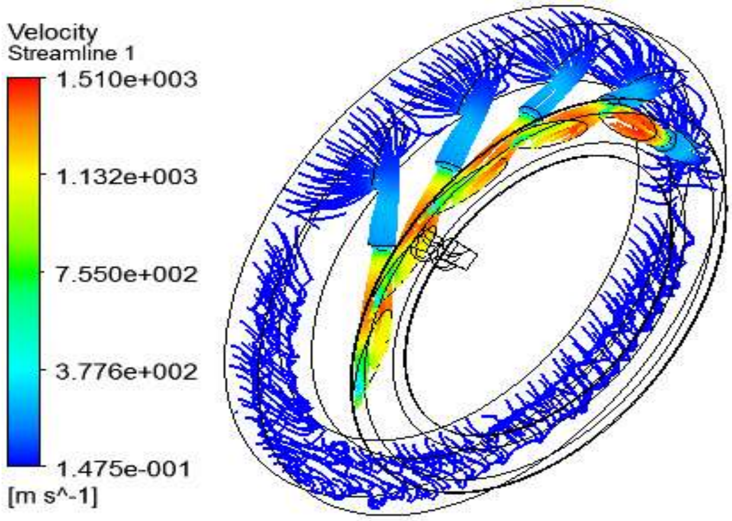


Fig. 22. - Speed parameter calculation results

As can be seen from Fig. 22, fluid inlets into the openings of the torque converter hub are stress and cavitation disturbance concentrators (marked with yellow and red colors). For example, when liquid enters the hole, there is a sharp narrowing of the hole, which is obtained due to the manufacturing technology of the hub, in which the pressure rises abruptly, thereby causing cavitation phenomena and high vibration zones.

And given the previous information, namely that the blades of the turbine wheel are welded, and not made by obtaining from a solid billet. And the turbine wheel, in turn, is fastened to the torque converter hub by means of landing, and is not made in one piece, hot deformation zones are formed [7].

To test the hypothesis, an analysis was carried out of the torque converter hub made from a solid billet.

The analysis showed a decrease in the zones of cavitation impact and displacement of the cavitation zone from the walls of the holes to the zone of the middle flow of liquid penetrating into the hole, thereby protecting the metal (Fig.23.).

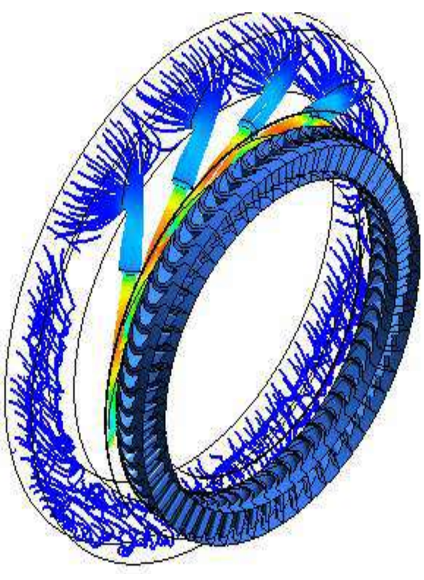


Fig. 23. - Analysis of the design of the torque converter hub made from a whole billet

Thus, various parameters of the torque converter operation were analyzed and the performance characteristics were obtained, as well as the internal frequencies at which the vibration of the main parts of the mechanism occurs (Fig. 25.).

In Fig. 11, yellow indicates the natural frequencies of the torque converter hub made from a solid workpiece, and in other colors, the internal frequencies of the component parts of the workpiece hub, made at the KLMZ plant, and in red the resulting oscillations of the product as a whole.

Also, during the process of obtaining a solution, data were obtained on the maximum speed of the hub, the pressure developed in the oil lines (Fig. 24).

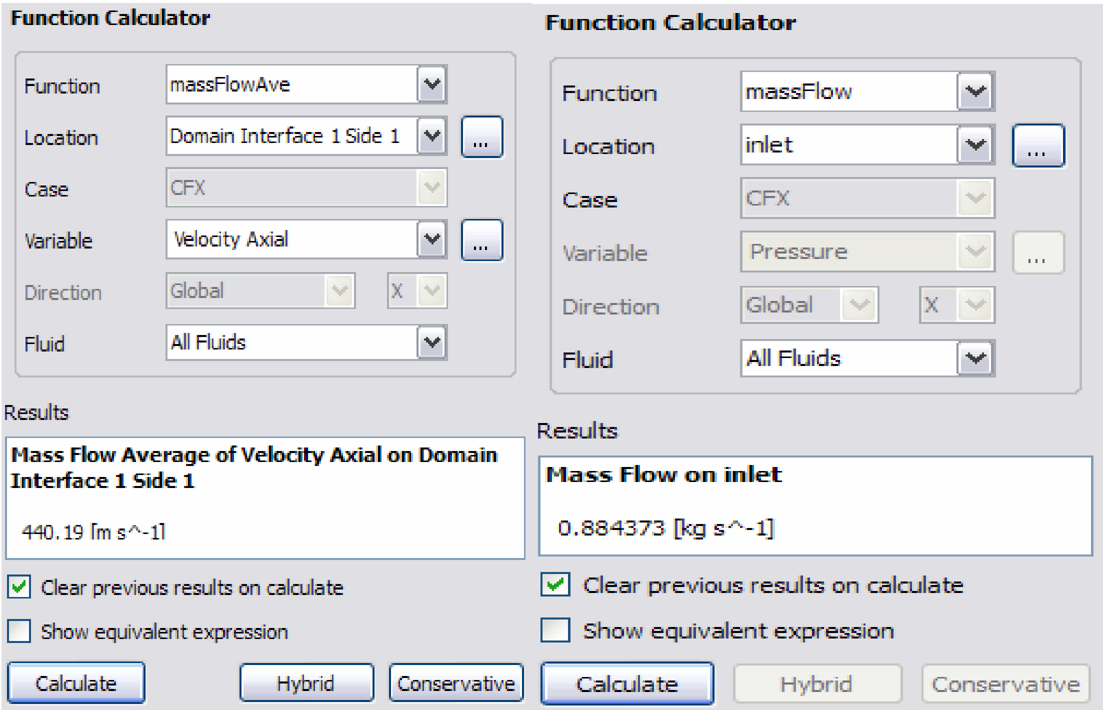


Fig. 24. – Obtained velocity and pressure values during the study

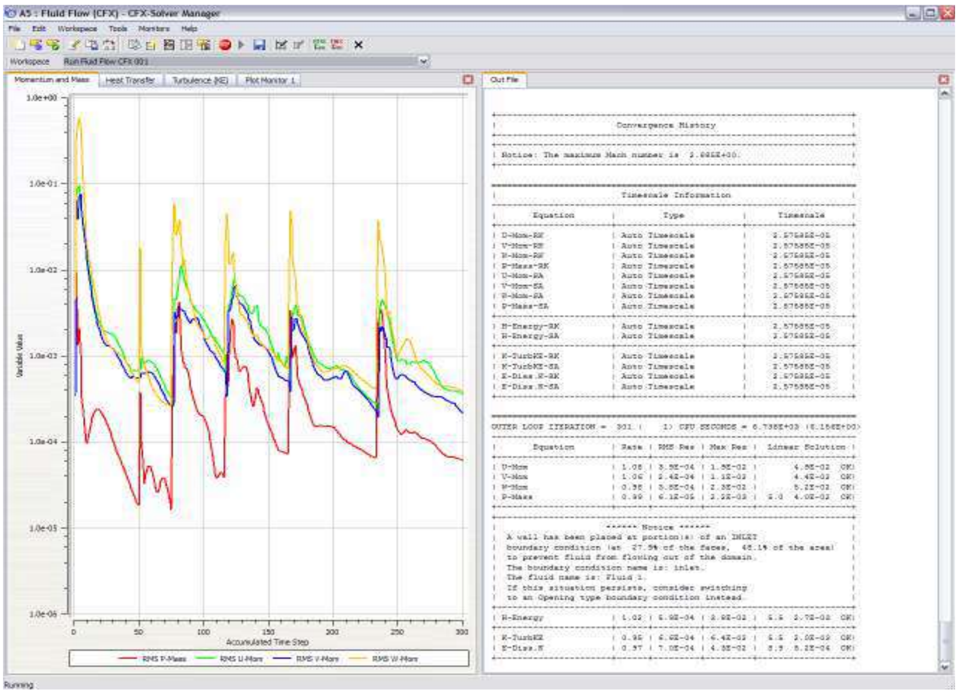


Fig. 25. - Analysis of the internal frequencies of the torque converter

Thus, it can be assumed that the manufacture of the impeller hub from parts, and the connection of these parts by welding and splined joints, was the cause of the development of all the above defects, since the resulting vibrations, as well as the presence of welds in the structure, and places for the development of defects, increase the risk explosive development of cracks and subsequent resolution or jamming of the entire assembly as a whole.

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