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MODELLING OF HEATING MODES OF ROTATING DISKS USING INDUCTION HEATING

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ABSTRACT

The disks of compressors and turbines of aviation gas turbine engines (GTE) under operating conditions are influenced significant mechanical and thermal loadings. Therefore the modelling of high-speed heating modes and thermostress state of rotating disks and rotors has the importance for increasing the operating time of GTE parts at non-stationary modes. The isothermal and thermal cycle tests of turbine disks with modelling of operational thermal and mechanical loadings are carried out on spin rigs with using induction heating. The methods of thermal cycle tests are developed for modelling of operational high-speed modes of heating GTE disks to reproduce cyclic thermal loading. Authors investigated the dependence of the extra power of internal heat sources in rotating disks versus frequencies of rotation between 10000-70000 r.p.m. in alternating electro-magnetic field. For this purpose the mathematical models are developed for calculation of power characteristics of induction heating system, developed new inductor designs and models of heating modes of rotating disks. The new design of flat inductors allows to raise accuracy of modelling and thermal control of the temperature fields in GTE turbine disks.

INTRODUCTION

The disks of compressors and turbines of aviation gas turbine engines (GTE) and power installations under operating conditions are under influence of rather significant mechanical and thermal loadings. Thermal streams in a zone of blades are characterized by key parameters of a gas stream: gas temperature and heat transfer factors from gas to a surface of blades. The temperatures in rim part of disks on an operating conditions reach 550, 750 °C, in blades – 800, 1100 °C and more. The average heating speeds of turbine disks of aircraft engines under operating conditions make 0,2÷1 К/с and the maximal speeds of heating of disks reach 2÷5 К/с. on separate heating regimes in the beginning of a flight cycle. Therefore the modelling of high-speed heating modes and thermostress state of rotating disks and rotors has the importance of in connection with increase in an operating time of GTE details at non-stationary modes. The isothermal and thermal cycle tests of turbine disks with reproduction of operational thermal and mechanical loadings are spent on spin rigs with use of induction heating [1-3]. One of fields of induction heating is realization of thermal the processes in rotation bodies for carrying out thermocycle tests of gas turbine disks on spin and specialized rigs.

The calculated-experimental methods of accelerated thermal cycle tests are developed for realization of modelling of operational high-speed modes of heating and cyclic thermal loading of GTE disks in view of the lead analysis of the test equipment and spin rig is advanced with use of induction heating and with new system of computer control of the electric drive of a direct current.

The usual system of induction heating for heating of turbine disks consists of several flat ring inductors, located on different radiuses of a disk. The specified heating system demands of use of several power supplies and accordingly raised power consumption. The lacks of the given system consist also that the inductors are located discretely on a surface of a disk and consequently there are local deviations (gradients) of temperatures ± 30÷40°C in a radial direction.

Authors first considered the heating the rotating disks in a variable electromagnetic field in view of additional allocation of internal power sources at high frequencies of rotation 20000-70000 r.p.m.

The induction heating allows to provide high speeds of heating and to receive the design non-uniform temperature distribution on radius of the disk corresponding operational conditions at tests on the spin rig [1-3].

At the present time works by calculation of heating of cylindrical preparations and creation of corresponding devices due to rotation in a constant magnetic field [4, 5] are known.

NOMENCLATURE

r	[m]	Radius of disk
T	[°C]	Temperature
x	[m]	Cartesian axis direction
y	[m]	Cartesian axis direction
z	[m]	Cartesian axis direction
P	[%]	Power

DESCRIPTION OF THE PROBLEM

The development of a heating methods of rotating disks with maintenance of the set temperature field of disks is an actual problem. For the decision of the specified problem it is necessary to solve problems of modelling of heating regimes of rotating disks. The choice of the inductors of a various configuration is necessary for maintenance of the designed temperature field of a disk. At thermocycle tests the maximal frequency of rotation of disks makes 5000 - 80000 r.p.m. The heating is carried out with the designed thermal streams.

The development and application rod and special flat inductors allows to eliminate local gradients of temperatures which are peculiar to systems of heating with discretely located inductors and to provide demanded distribution of thermal streams and to raise accuracy of reproduction of the set temperature distribution of a disk of variable thickness .

For the decision of the specified tasks the regimes of induction heating and mathematical models in program complex ANSYS are developed for calculation of electric, power characteristics of system of induction heating and modelling of temperature distribution on a disk of variable thickness in view of rotation.

THEORY

The numerical models in program complex ANSYS by authors for calculation of electric, power characteristics of system of induction heating and modelling of modes of heating of disks of variable thickness in view of rotation have been developed.

The investigations of influence of rotation frequency on allocation of power of heat internal sources in a disk due to two components of electromotive force have been carried out with use inductors of the different form. The first component arises on average frequency of a current in a variable electromagnetic field. The second component electromotive force arises at a rotation disk in the variable electromagnetic field created of a inductor, according to the law of electromagnetic induction. As a result the induced currents arise in addition. The specified component is small on small rotation frequency. The speed of change of a magnetic stream in a disk increases at increase of rotation frequency and induced electromotive force (the second component) becomes significant in a range of greater rotation frequencies. As a result the power of additional internal heat sources increases and the induction heating intensity raises of a rotating disk.

Thus, specific power P of induction heating is defined under the formula

$$P = P1 + P2 \quad (1)$$

where *P1* is the extracted power in a disk due to frequency of a current of an electromagnetic field, *P2* is the extracted power in a disk due to pulsations of a magnetic stream at rotation of a detail in a variable electromagnetic field.

RESULTS AND DISCUSSION

The non-uniform grid of final elements of disk of variable thickness for increase of accuracy of calculation was used. Figures 1 show the elementary mathematical model.

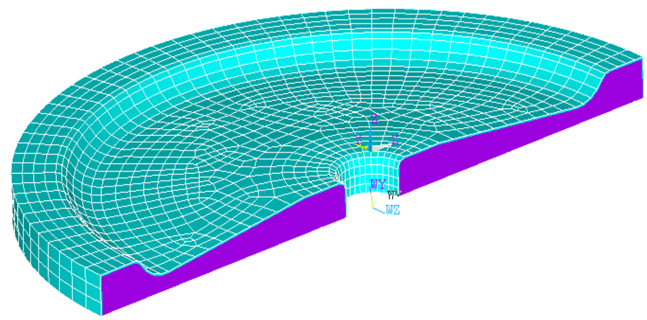


Figure 1 Geometrical model (a) and final element grid of disk of variable thickness

The constructed finite element grid of system "inductor-disk" contains approximately 170000 elements on the figure 2. The three-dimensional element SOLID117 is used for electromagnetic calculation of a harmonious problem in program complex ANSYS.

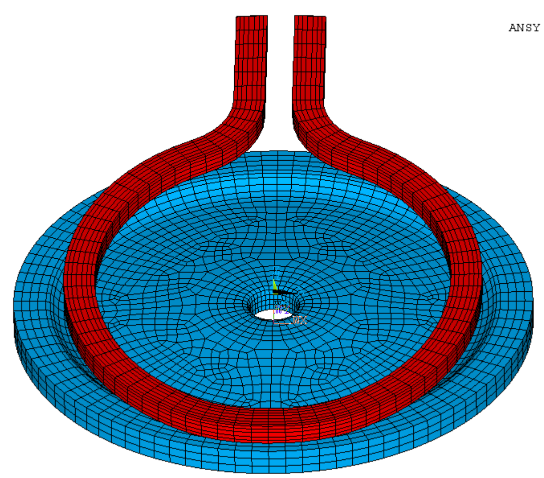
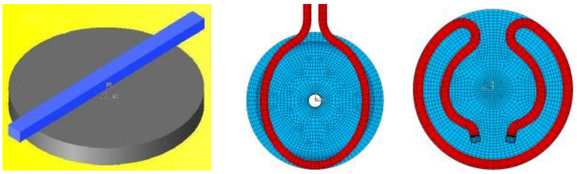


Figure 2 Final element grid of system "inductor-disk"

At increase rotation frequency the speed of change of a magnetic stream in a disk and induced electromotive force increase. As a result the power of internal heat sources increases and raises intensity of induction heating of a rotating disk. The calculated investigations of extracted power in the disk on view of the rotation using the rod and elliptical, loop inductors have been carried out (figure 3).



a) b) c)

Figure 3 Inductors for heating of disk: 1 – rod inductor, 2 – ellipse inductor, 3 - loop inductor

Figure 4 show the results of calculations of the extracted power in a disk at induction heating in view of rotation of a disk: 1 - loop inductor, 2 - rod inductor. The parameters of a mode: a current – 500 A and frequency - 2400 Hz, clearance - 10 mm.

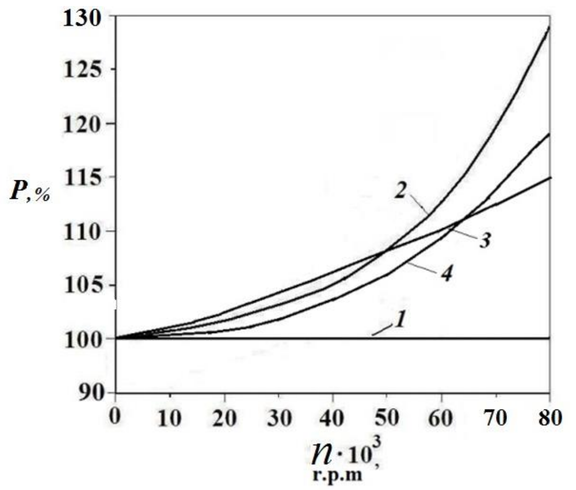


Figure 4 Dependence of allocated power in a rotating disk: 1 – without of rotating; with use - rod inductor (2), ellipse inductor (3), loopback inductor (4)

From the analysis (figure 4) of the received dependence of power (allocated in a rotating disk) it follows that influence of induced currents due to rotation disk, i.e. the increase of power of internal heat sources becomes essential at rotation frequencies above 30000 r.p.m. It is the additional factor power saving at carrying out of the thermocycle tests of disks with use of induction heating.

The developed models in complex ANSYS are used in carrying out on the basic of researches on influence of the various inductor configuration on temperature distributions in rotating GTE disks are resulted. In the specified calculation the greatest scope inductor surfaces of a disk is important. At rotation the most effective heating is reached in those ring zones of a disk which longer time are under sites. Hence, each such inductor site is characterized by the ratio of its width to a corresponding ring zone of heating. In this case the width of such inductor site of the complex form is defined on the basis of its crossing by a corresponding ring zone of heating.

The specified factors were considered in calculate investigations on influence of the various inductor form on distributions of temperatures in a rotating disk of variable thickness at a power supply of the different inductors (figure 5) by an identical current 500 A. The results of calculated modelling are submitted in figure 6.

Figures 6 show the temperature distributions with use inductors (figure 5) of the various configuration: *1* – ring inductor, *2* – ellipse narrow inductor, *3* – ellipse wide inductor, *4* - half-ring, *5* – half-loopback inductor, *6* - half-loopback inductor, *7* - loopback inductor, *8* – two loopback inductor, *9* – the design temperature distribution.

The analysis of temperature distributions with use various inductors in figure 6. The inductors *2*, *5* and *7* create the temperature distributions of also essentially distinguished from set. Thus narrow ellipse inductor *2* it is expedient to use for uniform heating of disks.

The temperatures distributions of inductors *8*, *4*, *3* and *6* are closest to the set temperature distribution *9* and specified inductors is possible to use at modelling thermal modes of disks. among inductors *8*, *4*, *3* and *6* the loopback inductor *8* allows to receive the most effective mode of heating of a disk. it provides higher speed of heating of average and central (nave) parts. it is important at thermocycles tests.

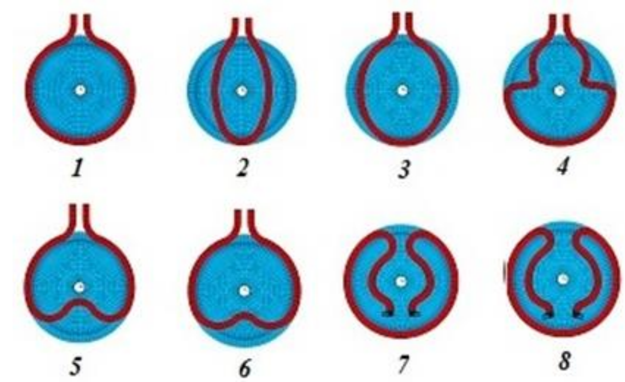


Figure 5 Inductors of the various configuration

Thus, the temperature distribution (*8*) has almost coincided with set distribution - *9*. Deviations of distribution *6* from the design temperature distribution 7 on radius of a disk do not exceed 10 °C.

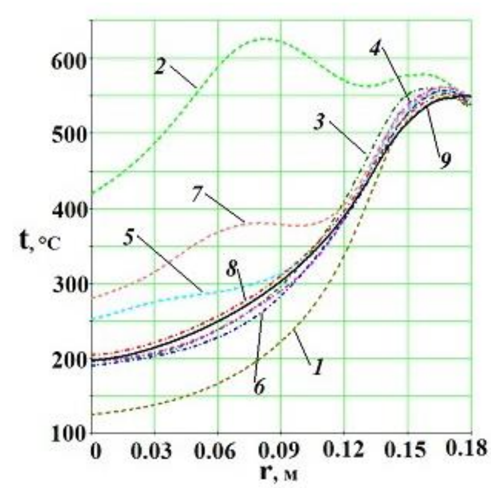


Figure 6 Temperature distributions of a disk depending on the inductor form (figure 6) in view of rotation

Besides, the inductor 8 has the highest efficiency among those inductors which coincide with required temperature distribution (9). On the basis of the lead calculations the optimum inductor design - loopback inductor 8 is chosen. The inductor provides the best approach of calculate temperature distribution of a GTE disk to design distribution 9.

The use of loop inductors designed using of the computer simulation and dual-frequency power supply system for loop inductors from one thyristor frequency converter (TFC) located on both sides of the disk allows to increase the effective temperature regimes in thermal cycling tests of rotating disks on the spin rig and improve the accuracy of modeling the experimental temperature distributions in disks in 2-3 times (with an accuracy of ± 10 ÷ 15 ° C) and reduce the number of inductors and power supplies in 1.5-2.0 times. The heating of the disk was provided by induction heating system with three TFC working at 2400-10000 Hz. The analysis of rapid heating also showed that with increasing heating rate in 5 times (from 2 K / s to 10 K / s) the performance-of the induction heating is increased in 2 times and the cost of electricity at the thermal cycling tests are reduced in 3 times.

The similar effect of heating (figure 4) can be received at rotation of a disk in the constant magnetic field created by constant magnets.

The manufacturing techniques of modern constant magnets are improved and have achieved the certain progress and now the constant magnets from редкоземельных alloys: neodymium- iron-boron and samarium-cobalt alloys it is possible to apply for heating of the rotating small disks. They are much stronger than usual ferrite magnets and magnets from other magnetic materials.

The investigations of a thermal state of the rotating disks in a constant magnetic field are expedient for carrying out with use of magnets from samarium-cobalt alloys since they have a significant magnetic induction and work at the increased temperatures up to 250-330 °C.

Electromotive force (EMF) it is induced at rotation of a disk in a magnetic field created by a constant magnet, according to the Faraday law of electromagnetic induction. Therefore there are induced currents. On small frequency of rotation the specified EMF it is small. At increase in frequency of rotation the speed of change (pulsation) of a magnetic stream in a disk increases and induced EMF becomes significant in a range of the big frequencies of rotation. In result the internal sources of heat increases and raises the intensity of heating of a rotating disk.

CONCLUSION

The developed three-dimensional models have been developed for investigation of calculation of electric and thermal parameters of inductors and electromagnetic fields at heating rotating disks of variable thickness in program complex ANSYS.

On the basis of the investigations of heating modes of disks in view of components of allocation of power in a detail due to current frequency and rotation frequency of a detail in a variable electromagnetic field are received. The specified factors expand opportunities of thermal managment of heating process of rotating details in a variable electromagnetic field.

Influence of rotation frequency on allocation of power of internal heat sources in a rotating disk with use different inductors has been analysed.

At comparison of modelling of temperature distributions with use inductors of the various configuration it is recommended loopback inductor.

The use of developed loop inductors allows to increase the effective temperature regimes in thermal cycling tests of rotating disks on the spin rig and improve the accuracy of modeling the experimental temperature distributions in disks of variable thickness.

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