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BIMETALLIC BLISK DESIGN FOR HIGH TEMPERATURE TURBINES OF GAS TURBINE ENGINE OF DIFFERENT APPLICATION

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Abstract

Problems that occur at the design of the cooled and uncooled turbine blisks including single crystal blades and ways of their solution are discussed in this report.
A process of designing based on calculations and experimental investigations, development of technology and manufacture of bimetallic blisk are shown on the example of a turbine wheel for a helicopter engine as a prototype.

Introduction

The design of a turbine wheel is based in particular on the requirement of obtaining high gas dynamic characteristics in operating conditions and corresponding design restrictions. The design includes gas dynamic calculations that allow choosing a configuration of a blade profile and number of blades taking into consideration conditions of maximum efficiency. Restrictions on the blade number are connected as a rule with requirements on strength and they also spread on dimensions of root joints which are necessary to locate on the disk rim. It is especially important for high temperature wheels of low-sized engines. The disk construction also depends on dimensions of root joints and must comply with requirements on strength. The disk becomes larger and the wheel weight – higher.

Besides the increase of the turbine speed rotation required for the compressor achieved higher dynamic pressure is restrained by the blade - disk root joints. Stress concentrations in the projections between grooves influence a life time.

The construction of free-root joint wheel allows locating the required number of blades on the disk rim, decreasing disk dimensions and consequently decreasing the wheel weight.

Lately due to the mentioned and other advantages the design of turbine wheel where blades and disk made of different alloys represent a one-piece construction (bimetallic blisk) becomes an advanced version. [1].

2 Tasks of design of turbine bimetallic blisks

The problems of the bimetallic blisk design include in particular a choice of alloy pairs, a choice of technology, design of the joint zone of heterogeneous materials and determination of properties of this zone, optimization of the design according to strength characteristics, blade vibration damping in the mono-wheel, cooling of the blisk rim and blades in the constructions with cooled blades and others.

Requirements on strength and designing of the blade profile and disk parts do not differ from conventional ones and must be taken into consideration at blisk development. The peculiarity of bimetallic blisk is the designing of a zone of the blades and disk part joint for which materials of different structure are used. Cast blades with poly crystal or single crystal structure are used for high temperature turbine wheels, and granulated alloys – for disks. Therefore one of the most important tasks is a choice of technology of the blades and disk hart joint.

2.1 Technology for manufacturing turbine bimetallic blisks

A hot isostatic pressure (HIP) process is the most appropriate method of the joint of heterogeneous materials [2].

A hot isostatic pressing (HIP) technology allows manufacturing bimetallic blisks by integrating cast blades and powdering disk section that operate in optimal thermal and loading conditions and have sufficient strength and reliability in the joint zone. This method of the joint of blades with a disk section allows to eliminate such complex structural mechanical joints, as lock and flanging joints, as well as welded and soldered joints that are stress concentrators.

These advantages can be implemented as a result of optimization of the HIP technology process, a choice of the rational configuration and location of the joint zone and required level of strength properties in the joint zone.

Based on the data of creep-rupture and low-cycle fatigue tests of samples and models composited of powder super-alloy and blade super-alloy, it has been found that strength characteristics of the diffusion layer with a thickness of 5-15 micron do not differ from strength of the adjoining layers of the bonded alloys within the spread range in time and number of cycles [3, 4].

2.2 Blisk engineering

The major purpose is design of blades and disk joint zone. Tests of bimetallic samples (single crystal + granulating alloys) have shown that real strength varies depending on stress strain state conditions.

Therefore optimization of connection zone of simplified blade butt with disk rim is possible under the condition that parts with tension stresses will prevail on this structure.

The structure of the joint zone of blades with disk is selected based on stress strain state calculations during operating conditions taking into account deformational, strength and physical characteristics of connecting parts materials.

The most rational configuration from the point of view of strength is determined on the base of numerical mathematical modeling by means of comparison of different schemes of blades and disk part joints using calculations of minimum margins of static capacity [5].

In order to ensure disk rim cooling it is necessary to provide an elongated shank that allows to deliver air into the cavities between a lower platform and disk rim and to solve a task of vibration damping.

Blisk with uncooled blades can be used for unmanned aircraft. As a rule it is necessary to cool wheel blades of large and medium sized engines particularly for maneuverable aircrafts. In case cooled blades the task of designing of bimetallic nonseparable turbine blades is complicated by the necessity of the cooled air supply into inner blade cavities.

For the joint uncooled unshrouded blades with a disk part for making of a relatively small dimension blisks the known method of placing a disk part and blades into a capsule can be used for conducting a HIP.

Let us consider method when the cooled blades with cores and the disk part are packed into the capsule. After HIP process the cores are leached. However the removal of the cores after HIP becomes difficult. It is not possible to ensure availability of the cavities and cooling lines through disk part.

A solution of this problem can be a removal of the ducts for blade cooling out of the zone of the sealed capsule. In this case the location of the blades and disk joint must have no cavities and all parts are packed into the capsule must have no cavities too.

Based on this idea a technological process of manufacturing bimetallic blisks including blisks with cooled single crystal blades has been developed [6].

The cooled blade and the system of cooled air supply into inner blade cavities are designed for a possibility of this technological process realization [7].

2.3 Scheme of a technological process for joint of blades and a disk

The scheme of a technological process for joint of blades and a disk is next.

- Casting of blades with shanks elongated by a value of fixation in the disk part;

- manufacture of a technological ring with holes for blade shanks;
- brazing of a technological ring with blade shanks;
- manufacture of a billet of the granulated alloy disk part;
- formation of a capsule and HIP process;
- removal of capsule and final mechanical and thermal treatments of blisk.

The proposed method is applied for development of a model blisk with uncooled blades for a helicopter engine.

The turbine wheel with a lock joint of blades and a disk are shown in figure 1 on the left. A model of the designed bimetallic blisk is shown in figure 1 on the right.

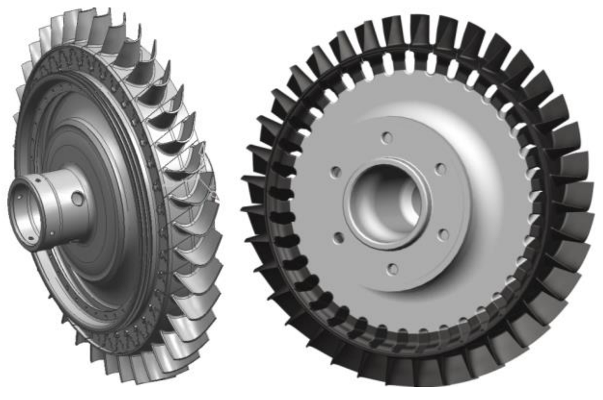

Fig. 1. The prototype wheel (on the left) and the model of the bimetallic blisk

Calculations of strength have confirmed the functionality of the designed blisk a given service life. The mass gain of the designed blisk as compared with the prototype wheel (with a lock joint of blades and a disk) is 23.6%.

This method is based on the formation of a capsule where the disk part and shank parts are located; the process of the diffusion joint of blades and disk materials takes place in capsule. In this case the blades must be preliminary fixed in the ring that allows to install them in the way as they will be located in the complete construction. Therefore at designing blisk blades it is necessary to provide an elongated shank of a four-angular cross section that must be inserted into the corresponding holes of the technological ring. One of important aspects of the suggested method of blisk manufacture is the insurance of hermiticity of a brazed joint of blades and technological ring that is a part of the capsule and subjected to high pressure and temperature at HIP.

Major stages of blisk manufacture are shown in figures 2-4.

Fig. 2. The single crystal blade (on the left) and the technological ring with blades installed in the equipment for brazing

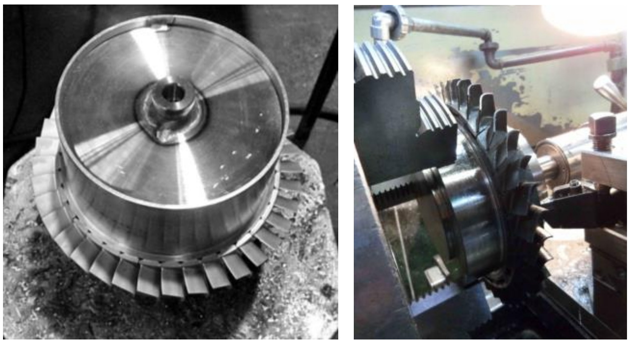

Fig. 3. The capsule with the blisk blank after HIP process (on the left) and the machining of the blisk blank

Fig. 4. The bimetallic blisk

2.4 Sample-simulators

The representative sample-simulators of the joint of a cooled blade with a disk parts made of heterogeneous materials have been developed for trying out the process of the cooled blades and disk part joint in the construction of bimetallic blisk with cooled blades.

A process of manufacture of sample-simulators is similar to process described above for the blisk with uncooled blades. The blades are cast of single crystal alloy and then ones are brazed to the technological plate (figure 5 on the left) and located into capsule (figure 5 on the right).

Fig. 5. The cooled blade brazed into the technological plate (on the left) and assembling of capsules

After the HIP process, thermal treatment, removal of the capsule (figure 6 on the left) and a final mechanical treatment the bimetallic sample-simulators of the joint of a cooled blade with a disk parts (figure 6 on the right) have been obtained.

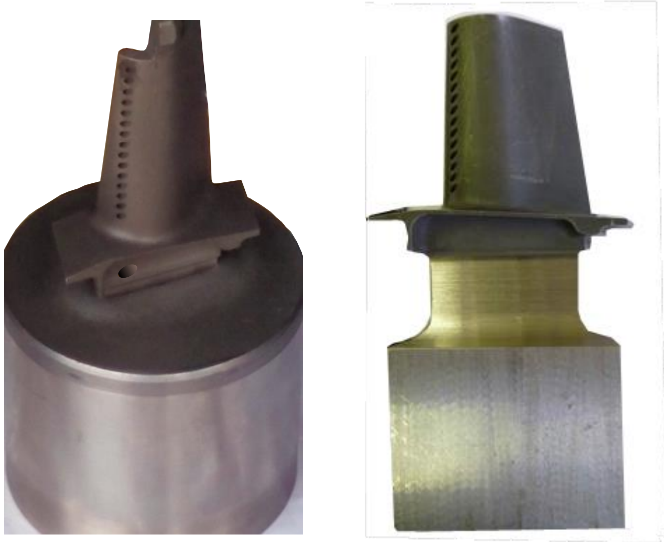

Fig. 6. The billet of sample-simulators of the joint of a cooled blade with a disk parts after HIP process (on the left) and one after mechanical treatment

2.5 Tests

The test results of the bimetallic bliss have confirmed strength reliability of the zone of the blades and disk joint and the blisk itself.

The experimental investigations of possibility of vibration damping for blades in the bimetallic blisk have been conducted for blisks of three constructions that differ by the blade shank configuration [8, 9]. The test results have confirmed a possibility of effective vibration damping of blades in blisk by means of dry friction dampers installed below the blade platforms.

It has been established on the example of tested blisks that the most rational for effective vibration damping is a construction with blade elongated shanks.

The application of dampers in the constructions of the blisk with elongated shanks allows to increase their efficiency in comparison with the dampers of the same mass for construction with shorter shanks in several times.

3 Recommendations on designing of bimetallic blisks for turbine wheels

Based on the results of bimetallic specimens testing and strength analysis of bimetallic models and wheels, recommendations with respect to design of the blade-to-disk joint zone have been made.

It is expedient to use the HIP technologies for blisk manufacture. The preliminary cast single crystal blades are to be jointed with billet of the central disk part by interlayer made of disk material powder.

Based on the analysis of mechanical tests of compound samples and investigation of the structure of the joint zone one can select pairs of alloys.

The areas of blade shank joints must have a smooth transition to projections on the disk periphery.

It is necessary to provide lack of cavities in the zones of joint of cooled blades and disk part as well as in disk parts.

The blades must have elongated shanks for installation into the equipment, arrangement of ducts for air supply and damper inserts and blowing for the wheel rim part cooling.

For insurance of strength reliability the area of blades and disk joint should be located outside zones of stress concentrations and zones subjected to shearing loads.

All investigations have shown that bimetallic HIP blisks may be successfully used in gas turbine engines.

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