INCREASING THE OPERATIONAL LIFE OF MPM-20 JET ENGINE USING UNCONVENTIONAL TECHNOLOGIES

Conference Paper · January 2014

Cúttová Miroslava
Technical University of Kosice - Technicka univerzita v Kosiciach

Jozef Čerňan
University of Žilina

Ratkovská Katarína
University of West Bohemia

INCREASING THE OPERATIONAL LIFE OF MPM-20 JET ENGINE USING UNCONVENTIONAL TECHNOLOGIES

CÚTTOVÁ Miroslava, ČERŇAN Jozef, RATKOVSKÁ Katarína

The article analyses the issue of enhancing the performance and service life of the MPM-20 jet engine applying protective coatings on hot engine parts. It deals with the analyses of these parts from the structural and chemical composition point of view and their conditions of operation. Consequently selected types of protective coatings (metal and ceramics) in terms of meeting the desired requirements for the surface treatment of parts in the MPM-20 engine are discussed. It ensures increasing of its service life and extend its period of operation without the need to reduce the nominal power, or other more complex structural modifications.

Keywords: jet engine, protective coating, thermal plasma spraying, increasing of performance and efficiency

Introduction

Operation of aeronautical machinery is always limited by its technical operation time. However complexity and robustness cause that the operating life of the individual parts differs. So some aeronautical machinery is aging faster morally than physically. As a result, it happens that some of aeronautical machinery, despite still functional, becomes unusable in the air traffic. It is, for instance, also some aircraft engines, or their associated starting parts. The effort is then to use these functional units for other purpose, such as in energetics [1]. Similarly it is also in the case of TS-20/21 turbostarter of manufactured in Soviet Union, which, by its nature, can be converted into the energy producing device or used as an experimental laboratory jet engine [2]. But forasmuch as TS-20/21 was not designed for a long-term operation (only for a short time needed for an engine to start up), it was necessary to decrease temperature in its functional parts. It was done by the control of the fuel flow, thus by its power output reduction, because operation using the original nominal power would destroy the engine in a long-term operation. In order to increase its operation time, durability and also performance, it is necessary to make certain structural modifications. It can be realized by applying a protective material in the form of thermal barrier coatings on hot engine parts and other types of coatings for wear resistance and corrosion resistance improvement, as well as the tribological properties of traction and bearing systems parts exposed to high temperatures.

2. Characteristic of the MPM-20 jet engine

Small jet engine marked as MPM-20 was made by constructional modification of the TS-20/21 turbostarter (Fig.1) for the laboratory experimental measurements in the facilities of the Faculty of Aeronautics at the Technical University of Košice [3]. The MPM-20 aviation jet engine is made up of following main components:

- a mixed (axial-radial) air intake system,

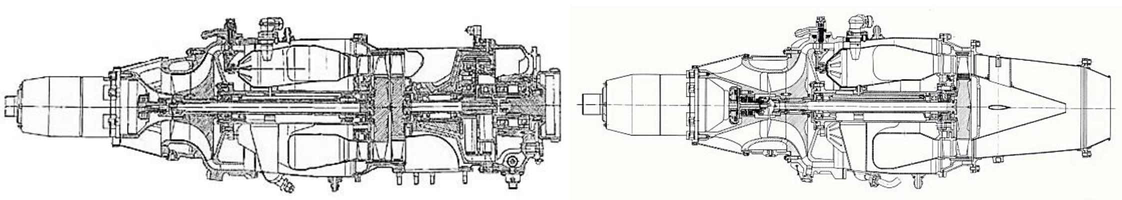
- a centrifugal compressor with a single sided impeller,

- an annular combustion chamber,

- a single stage axial uncooled gas turbine of the reaction type,
- an output system with the fixed outlet nozzle.

Fig. 1: Turbostarter TS-20/21

The air intake system of the MPM-20 engine provides a continuous supply of the required airflow to the compressor. Compressed air from the centrifugal compressor enters the combustion chamber. The flow is then divided into primary (30%) and secondary (70%) airstream. The primary airflow enters the flame tube of the combustion chamber and then the air is mixed with fuel for combustion. The secondary airflow is lead around the flame tube to provide cooling of the gas flow. Gas from the combustion chamber enters the gas turbine, where the expansion occurs. The hot gas enters the output system of the engine. The exhaust should direct the hot gasses away from the engine in the axial direction and transform unused heat and gas pressure energy into the kinetic energy, which creates a reactive thrust. Schematics of the TS-20/21 turbostarter and MPM-20 engine are shown in Fig.2.



a) **b)**

Fig. 2: Schematics a) TS-20/21, b) MPM-20

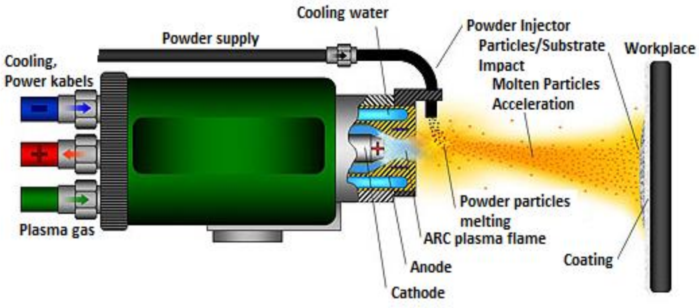
Among the most often damaged parts of the jet engine include:

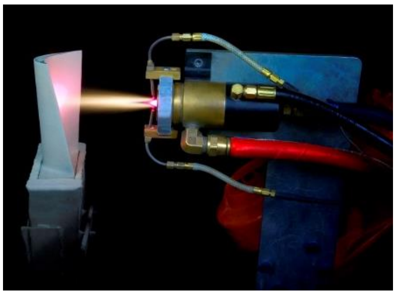
- an air intake system and compressor (mechanical damage),
- a combustion chamber and gas turbine (thermal stresses).

The long-term operation of the MPM-20 small turbojet engine causes an increase of the thermal stress of hot engine parts and the engine can be easily damaged.

3. Technology of the thermal plasma spraying

The use of thermal plasma spraying (TPS) in the production of the protective coatings is characterized by a high energy density and high temperature of the plasma flame [4]. In the TPS technology are mainly used additional materials in a powder form, which are added into the flow of highly concentrated plasma with high temperature. The output velocity of the plasma achieves high values, therefore particles of additive materials are a carriers of the high energy (Fig.3a).





a) **b)**

Fig. 3: Thermal plasma spraying [5],[6]

The high temperature of the plasma flame allows creation of coatings from different materials independently on the melting temperature. Powders based on cobalt Co and nickel Ni, which are resistant to abrasion and corrosion, are most commonly used. Restriction occurs only in terms of the oxidative character of the liquid stabilization of plasma flame, because a metallic material leads to the increased oxidation [4]. On the Fig.3b the application of the protective coating using thermal plasma spraying technology on the blade of the engine is shown.

3.1 Additive materials for protective coatings

During the application of the protective coatings on the components of the engine it is necessary to choose appropriate coating technology, type and form of the additive material. We have to respect their mutual characteristics, such as the melting temperature, protection against abrasion, corrosion, hardness increasing and etc. In the production of the protective coatings by thermal plasma spraying technology additive materials in a powder form are used. These additive materials can be produced almost from the all materials, so their use is very effective; additive materials in the form of a powder based on pure metals, metal alloys, ceramic materials, materials with an exothermic effect and the special additional materials are most often used (Tab. 1).

Tab. 1: Overview of the additive coatings [7],[8]

Type of the material	Additive material in the powder form	Range of graininess [μm]	Melting temperature [°C]	Use of the protective coating
Metals	**Al**	10-90	658	corrosion protection
	Ni	5,6-90	1454	good adhesion
Metal alloys	**NiAl**	5,6-125	1420	good adhesion
	NiCr	5,6-90	1400	corrosion protection
	NiCrAlY	45-90	1050	corrosion protection and dilation
	CoCrAlY	45-90	850	corrosion protection and dilation
Ceramics	**$Al_2O_3 + TiO_2$**	5-63	1950	corrosion and wear protection
	$Al_2O_3 + Cr_2O_3$	5,6-63	2000	wear protection
	$ZrO_2 + Y_2O_3$	5,6-63	2700	corrosion and wear protection

4. Material analysis of selected thermally stressed engine parts

For a convenient proposal of appropriate coatings on heat-exposed parts of the engine, it is necessary to know their materials, physical properties - thermal expansion coefficient and the exact conditions, under these parts are working. For a lack of an existing manufacturing documentation the reverse engineering of selected parts of the engine was realized.

4.1 Combustion chamber

The combustion chamber of the MPM-20 engine is associated, with a direct flow and four heads. It consists of two main parts:

1. Combustion chamber housing,

2. Flame tube.

A combustion chamber of the engine - Fig. 4 is a cylindrical-shaped self-supporting structure made by welding a steel alloys with a thickness of 1 mm.

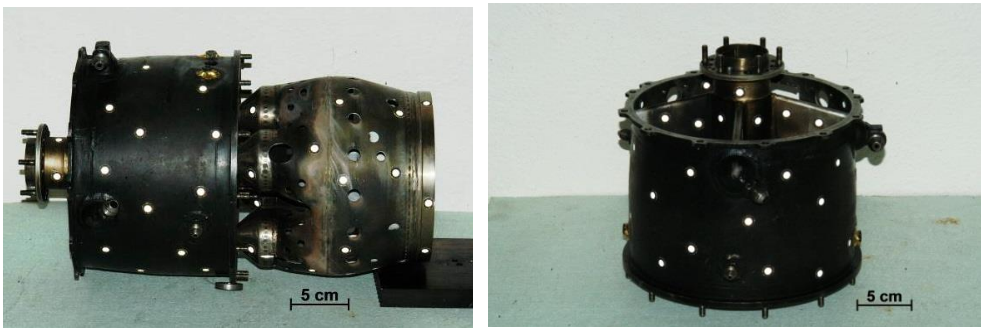
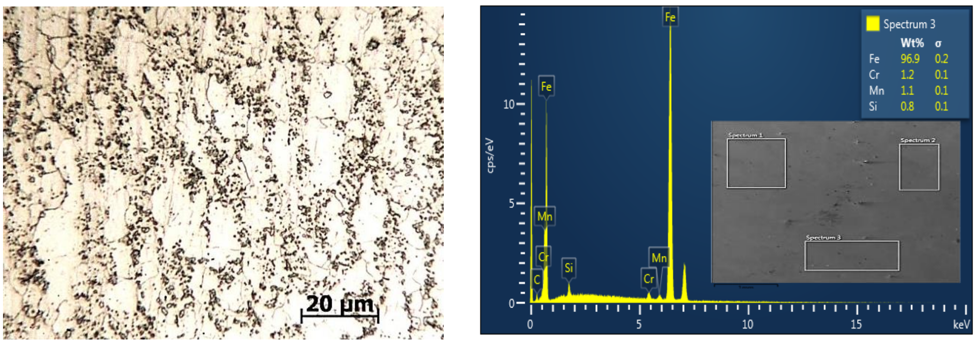


Fig. 4: Appearance of combustion chamber with extended flame tube

For the accurate identification of the alloyed steel type available metallographic analysis and also the analysis of basic elements by spectral emission were used. For this purpose it was necessary to remove a small portion of the housing material from already disposed engine. Measurement of hardness, tensile strength testing and analysis under the microscope revealed the following facts:

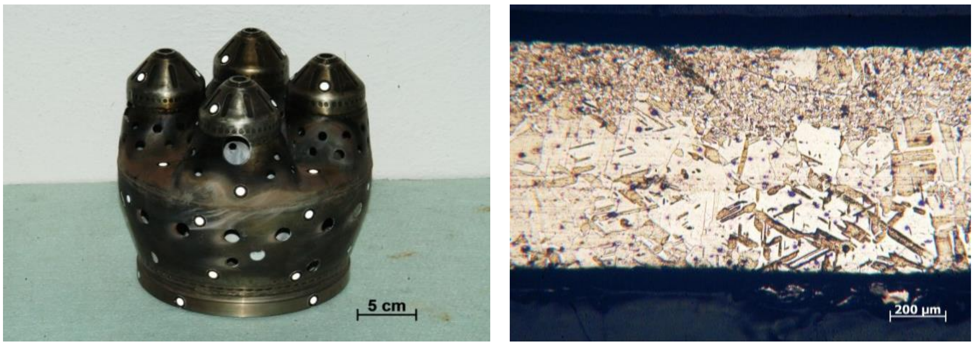


a) **b)**

Fig. 5: Microstructure of steel casing and EDX analysis of its elements

On the basis of metallographic observations it can be concluded that the structure of the material is ferrite - pearlite, more specifically it is a globular pearlite with well spheroidized carbides - Fig. 5a. As a result it can be assumed that it is an alloy steel after thermal refining. The carbon content can be estimated on the basis of the proportion of pearlite in the structure, as well as thanks to the fact that the material was welded. Weldable steels have carbon content up to 0.25 to 0.31 wt %. To obtain preliminary content of elements EDX qualitative spectral analysis in the electron microscope Tescan Mira 3 was performed. The result is shown in Fig. 5b. Measuring of the material hardness showed that the HV 10 hardness is about 250. Based on the conversion tables it can be concluded that the strength of the material is about 700–800 MPa, which was consequently confirmed by a static tension test at 20 °C. The composition and properties of the studied steel approximates our normalized steel STN 42 14331. However, since it is a product of the former Soviet Union, it is necessary to take into account the Russian equivalent of this steel, which is in accordance with GOST standards steel marked as Chromansil - 25 CrMnSiA (25ChGSA) [9]. It has the coefficient of thermal elongation within the range of 12,2 $.10^{-6}$ K^{-1} at 20 °C to 14,4 $.10^{-6}$ K^{-1} at 600 °C. The inner surface of the housing had a different coloration. However, it can be removed using the acetone diluent. It is a painting based on Al and Zn, which was used to partially protect steel casing chamber from the radiant heat of the flame tube.

The flame tube of the combustion chamber - Fig. 6a is an associated type. It has four tubular elongated heads and a common annular body. The outer and inner shell of 1 mm thickness is in the front section coupled with four conical tubular heads. In the back section it has an outer and inner shell of flange.



a) **b)**

Fig. 6: Flame tube and its microstructure affected by heat

Microstructure - Fig. 6b shows inhomogeneous structure of nickel austenite type with a large incidence of twins [10]. On the inner side the fine-grained structure can be seen, which may be a result of a long term exposure to high temperatures.

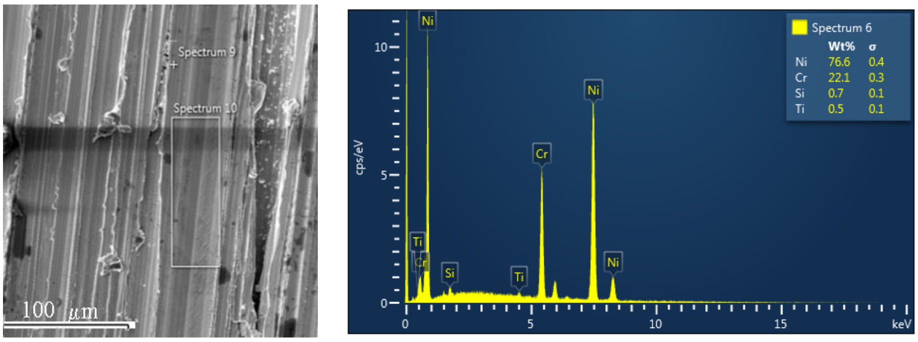


Fig. 7: EDX analysis of the flame tube

Qualitative spectral analysis by EDX showed following results - Fig. 7, where a high proportion of Ni, Cr and alloying additives in the form of Si, Ti can be seen. The mechanical properties of the flame material on the basis of the static test strength and hardness test were determined. Material has a maximum tensile strength of 630 MPa and yield strength of 394 MPa at a temperature of 20 °C and HV 10 hardness value is about 216. From the measured and observed results it can be concluded that in GOST standards with given composition and properties correspond to the nickel alloy designated as EI 435 (ChN78T), which is primary used for the combustion chambers operating at temperatures of 1000 °C [11]. The thermal elongation coefficient is 12,2 $.10^{-6}$ K^{-1} at 20 °C and 15,5 $.10^{-6}$ K^{-1} at 700 °C.

4.2 Turbine stator vanes and turbine rotor blades

The flow guidance system of the gas turbine has 19 guidance vanes, which were made by the casting of heat-resistant nickel-based alloys. In this case they have the same composition as the rotor blades, so it was not necessary to analyse the material. To the disc of the engine gas turbine 27 uncooled rotor blades are mounted - Fig. 8, manufactured using precise vacuum casting method and creep resistant nickel based alloy.

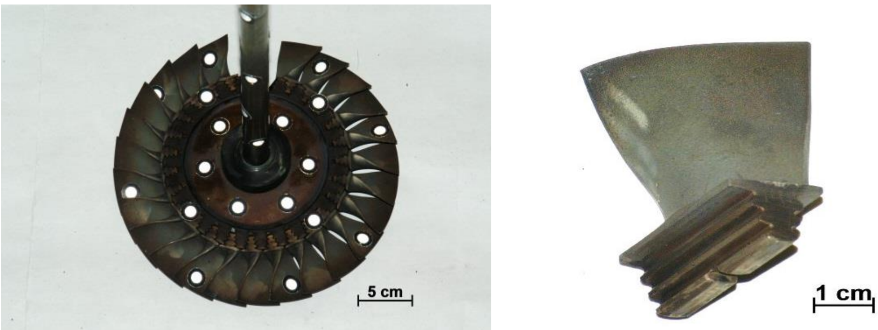
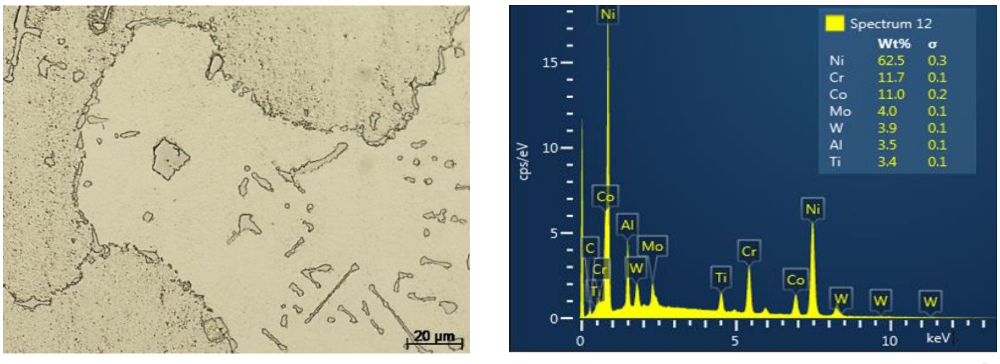


Fig. 8: Appearance of turbine rotor with dismounted blade

Appearance and size of the blade is shown in Fig. 8. Initial assumptions rumoured about the possibility of producing these blades by casting. This assumption was proved to be correct and was confirmed, metallographically. Microstructure of as - cast superalloy consists of a significant dendritic segregation caused by particles and chemical heterogeneity of primary and secondary $M_{23}C_6$ MC carbides - Fig. 9a. Primary carbides (Ti, Mo and W)C are presented as block shape particles mainly inside of grains. Secondary carbides are presented as a “Chinese” script shape particles on grain boundaries [12].



a) b)

Fig. 9: Microstructure and EDX analysis of the blade material elements

Qualitative chemical analysis of the material has been made on section of cut surface perpendicular to the blade axis in the root just above tree type attachment. The EDX analysis revealed the following facts - Fig. 9b. The high proportion of Ni, Cr and Co blended with reinforcing additives of Mo, W, Ti is obvious and also Al, which also partially improves heat resistance by formation of oxides. Due to the small size of turbine blade it was not possible to cut a relevant sample for the static test strength, so we only made hardness tests, from which an approximate value of strength using of conversion tables were set, which is for the HV10 of 380 about 1220 MPa. Comparing this material with known Ni - alloys for castings from former USSR [13], which were used as structural materials for aircraft turbine engines, gives us the possibility to assign it to a standard alloy of the ZS 6K type, which has corresponding chemical composition and mechanical properties. Its thermal expansion coefficient has a value of $11{,}5.10^{-6}$ K^{-1} at 20 °C and at 800 °C to $14{,}8.10^{-6}$ K^{-1}.

5. Modification of the MPM-20 engine

Thermal plasma spraying allows applying a protective coating on the surface of the parts of the MPM-20 engine, which enables to achieve resistance against higher operating temperatures in a nominal mode and to extend the operation time of the engine. Also the corrosion and wear protection will be improved. On the Fig. 10 the materials selection is shown, that would enhance the properties of the thermal stressed parts of the MPM-20 engine. The selection of materials was made on the basis of previous material analyses of selected parts of the engine.

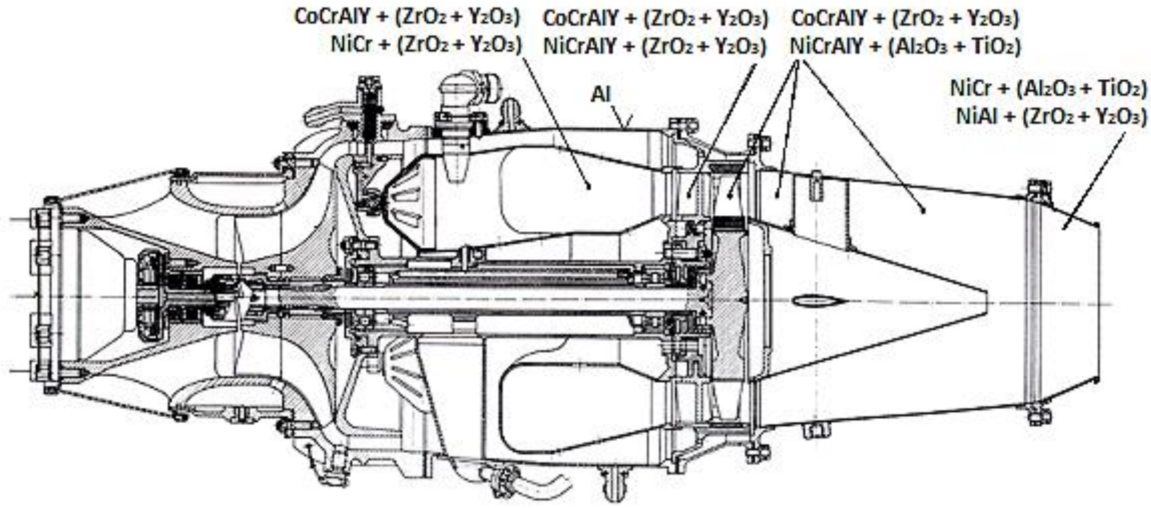


Fig. 10: Protective coatings proposal for various parts of the MPM-20 engine

The protective coating, which was selected for the MPM-20, is formed from the intermediate layer of metal alloys and the topcoat, which is composed of ceramic materials. On flame tube of the combustion chamber appeared to be the most appropriate the protective coating formed from the CoCrAlY or NiCr interlayer and with the $ZrO_2+Y_2O_3$ topcoat. On the stator vanes and rotor blades of a gas turbine coating formed from the NiCrAlY interlayer and $Al_2O_3+TiO_2$ topcoat or coating formed from the CoCrAlY interlayer and $ZrO_2+Y_2O_3$ topcoat can be used. The outlet nozzle of the output system from the heat resistance steel after engine modification was made therefore protective coating formed with NiCr or NiAl interlayer and $Al_2O_3+TiO_2$ or $ZrO_2+Y_2O_3$ topcoat can be used. For the combustion chamber housing we have proposed from the inside aluminium coating.

Conclusion

The aim of this paper was to select the most appropriate types of protective coatings for thermal plasma spraying for selected heat-stressed parts of the small MPM–20 turbojet engine. Protective coatings will act firstly as a thermal barrier and secondly as a deposition material for lowering the difference in the thermal expansion between used thermal barrier ceramic material and base materials. For a proper proposal of coating type it was necessary to know the materials of selected engine parts. As used material were not inscribed in the technical documentation, it was necessary to carry out the analyses, which would clearly define its normative inclusion. In such a way, the following results can be concluded:

- Combustion chamber housing, which is from the selected parts the less thermal stressed, according to the results of analyses can be assigned as a material of GOST standard steel 25 CrMnSiA (25ChGSA); our equivalent would be STN 42 14331. For this type of material operating in the given conditions, aluminium coating from the inside have been proposed.

- Flame tube of the combustion chamber is according to the analysis probably made of a nickel superalloy EI 435 (ChN78T), working at temperatures up to the 1000 °C. The protective coating of $ZrO_2 + Y_2O_3$ with NiCr intermediate layer is proposed.

- Stator vanes and rotor blades of a gas turbine in this case of precision casting from the ZS 6K nickel superalloy reliably working at temperatures up to 1200 °C are made. Protective coating could be formed from the NiCrAlY and from the topcoat of $ZrO_2 + Y_2O_3$.

- Similar coating type to the nozzle made of the heat-resistant steel can be applied.

The purpose of these coatings is to extend the MPM-20 engine operational life when operating at its nominal mode, without limitation of the T_3c temperature (the temperature of gases before the gas turbine).

Literature

[1] POLANSKÝ, J. - HOCKO, M.: Možnosti konverze leteckých pomocných pohonných jednotek na pozemní energetické systémy. In: Strojárstvo. Jún (2009), p. 211-213. - ISSN 1335-2938.

[2] HOCKO, M. - ŽIŽKA, V.: Návrh úpravy turbínového spouštěče TS-20B na experimentální turbohřídelový motor. In: Power System Engineering, Thermodynamics and Fluid Flow 2012: 11th conference: sborník příspěvku: 13. - 15.6.2012: Srní. - Plzeň: ZČU, 2012, p. 1-8. - ISBN 978-80-261-0113-0.

[3] FŐZŐ, L. - ANDOGA, R. – MADARÁSZ, L.: Mathematical model of a small Turbojet Engine MPM-20. In: Studies in Computational Intelligence. Vol. 313 (2010), p. 313-322. - ISSN 1860-949X.

[4] AMBROŽ, O. – KAŠPAR, J.: Žárové nástřiky a jejich průmyslové využití. Praha: SNTL, 1990. p. 320. ISBN 80-03-00347-4.

[5] Plasma spraying: [online]. <http://www.ep-coatings.co.uk/processes/plasma-spraying/>.

[6] Plasma thermal spray coating: [online]. <http://saeedcoatings.com/?page_id=28>.

[7] AMDRY: Amdry coating materials. Switzerland: Sulzer Surface Tech, 1992.

[8] HILLERY, V. R. et al.: Coatings for High-Temperature Structural Materials: Trends and Opportunities. Washington, D.C.: NAP, 1996.

[9] KLJUEV, M. M.: Žaropročnyje stali i splavi, spravočnik. Metallurgija, Moskva 1983, p. 191.

[10] ASM Handbook comitee: Metallography and microstructures, Volume 9, ASM Handbook, ASM International, 2004, p. 2733.

[11] SAMIZDAT: Konstrukcionyje materiali dľa aviacionnych GTD, KJUV, 2010, p. 22.

[12] BELAN, J.: Quantitative metallography of heat treated ŽS6K superalloy. In: Materials Engineering - Materiálové inžinierstvo. Vol. 18 (2011) p. 121-128. ISSN 1335-0803.

[13] SIMS, Č. – CHATEĽ, V.: Žaropročnie splavi, Metallurgija, Moskva, 1976, p. 566.

Acknowledgment

Authors would like to take this opportunity to thank the staff of the Institute of Geotechnics of the Slovak Academy of Sciences and to staff of the Laboratory of Intelligent Control Systems of Jet Engines for helping with realization of material analysis of selected parts of the MPM-20 engine.

Ing., CÚTTOVÁ Miroslava, Technical University of Košice, Faculty of Aeronautics, Department of Aircraft Engineering, Rampová 7, 041 21 Košice, +421 55 602 6171, miroslava.cuttova@tuke.sk

Ing., ČERŇAN Jozef, Technical University of Košice, Faculty of Aeronautics, Department of Aviation Technical Studies, Rampová 7, 041 21 Košice, +421 55 602 6159, jozef.cernan@tuke.sk

Ing., RATKOVSKÁ Katarína, Faculty of mechanical engineering of University of West Bohemia, Department of power system engineering, Univerzitní 22, 306 14 Plzeň, +420 37763 8128, ratkovsk@kke.zcu.cz