THE TRANSFORMATION OF THE TURBO-PROPELLER ENGINE TO POWER GAS TURBINE

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Summary. This work is dedicated to the transformation of aviation turbo-propeller engine AI-24 for energy purposes. The paper provides an analysis of engine construction, design modifications analysis of main components for energy use, as well as analysis of major engine systems. Thermal cycle engine is calculated for first cruise mode. And also it discusses the legislative formalities associated with aircraft engine modifications for energy purposes. The paper processed requirements for such equipment. It is the establishment of framework proposal facilities for electricity production based on the use of turbo-propeller engine AI-24 and describes the different elements of the proposal. The work is also devoted to analysing the actual state of the engine and its inspection. It is a procedure for checking the actual condition of the air turboshaft engine. In the end, it evaluates the use of motor AI-24 for power generation purposes and proposes the possibilities for solving problems of implementation of aircraft turboprop engines for energy purposes.

Keywords: transformation of turbo-propeller engine; power gas turbine; turbo-propeller engine AI-24; environmental standards and regulations

1. INTRODUCTION

For twenty five years by now the redundant and decommissioned military equipment of the Slovak Armed Forces has come to the Base of redundant and useless material in Nemecká, which was established in July 2002 after reorganization changes, when great amount of military equipment and material has been declared as redundant. A part of the material has been gradually sold off or transferred without payment to cities, to the third sector or other organizations [3]. A certain part of redundant special ground and aviation military equipment came to the Military historic museum in Piešťany and in Aviation Museum in Košice, where it became a part of museum collections. Redundant and useless artillery, tank and aviation ammunition, missiles and other types of explosive material have been professionally neutralized in delaboration plants in Nováky or it has been disposed on dedicated areas. A similar destiny is assigned for spare parts, which were delivered to the military ground and aviation equipment being used. Despite the efforts for an effective and useful application of redundant special military equipment and material, its significant part comes to an end as iron scrap material in metallurgical works. Such material includes also aviation turbo compressor engines (ATCE), which were not sold in period, when their technical lives were interested for foreign user or to be used as a museum exhibit in any aviation museum. Ecological disposal of such material is often charged with additional costs, connected with its dismantling and sorting of individual parts by material classes.

After partition of the Czechoslovak federal republic as by 1 January 1993 within the division of the property of the Czechoslovak Army in 2:1 rate, the Slovak Republic has got 27 types of aviation equipment, in which 23 types of ATCE had been used (7 types of aviation turbo-jet engines (ATJE), 5 types of aviation by-pass turbojet engine (ABPTJE), 3 types of aviation turbo-propeller engines (ATPE), 3 types of aviation turbo-shaft engines (ATSE) in various versions and 5 types of auxiliary power units (APU) [1, 4, 15], which are shown in the Tab 1.

Table 1 Aviation turbo-compressor engines used within the SR Armed Forces Air Force

Ser.	Type of engine	Kind of engine	Type of aircraft	Numbers in Air Force of the SR AF	Remark
1.	**M-701**	ATJE	L-29	0	Cancelled
2.	**AI-25TL**	ABPTJE	L-39ZAM, L-39CM	3+4	In operation
3.	**AI-20**	ATPE	An-12	0	Sold
4.	**AI-24**	ATPE	An-24, An-26	0	Cancelled
5.	**AI-25**	ABPTJE	Jak-40	0	Cancelled
6.	**M-601E**	ATPE	L-410UVP, L-410UVP-E20	5+1	In operation
7.	**AE2100-D2A**	ATPE	Alenia C-27J Spartan	2	In operation
8.	**R-13F-300**	ATJE	MiG-21R, MA, MF, UM	0	Cancelled
9.	**R-11F2M-300**	ATJE	MiG-21US	0	Cancelled
10.	**RD-33**	ABPTJE	MiG-29AS, MiG-29UBS	1+20	In operation
11.	**GTD-350**	ATSE	Mi-2	0	Cancelled
12.	**TV2-117**	ATSE	Mi-8	0	Cancelled
13.	**TV3-117**	ATSE	Mi-17M, Mi-17LPZS	5+4	In operation
14.	**TV3-117**	ATSE	Mi-24D, DU, V	0	Cancelled
15.	**T700-GE-701C**	ATSE	Sikorsky UH-60 Black Hawk	2	In operation
16.	**AL-21F-3**	ATJE	Su-22M-4, UM-3K	0	Sold
17.	**R-95Š**	ATJE	Su-25K, UBK	0	Sold
18.	**D-30KU-154**	ABPTJE	Tu-154B-2	0	Cancelled
17.	**TR3-117**	ATJE	Tu-143 (VR-3 Rejs)	0	Cancelled
19.	**Safír-5**	APU	L-39	7	In operation
20.	**Safír-5G**	APU	L-39MS	0	Sold
21.	**RU-19-300**	ATJE	An-24, An-26	0	Cancelled
22.	**AI-9V**	APU	Mi-17, Mi-24	9	In operation
23.	**TS-21**	ATSE	Su-22M4, UM-3K	0	Cancelled
24.	**TA-6A**	APU	Tu-154B-2	0	Sold

Applicability of particular types of ATCE for alternative functions is largely dependent on a concept of a given engine. Aviation turbo-jet engines M-701, R-13F-300, R-11F2M-300, AL-21F-3, R-95Š, TR3-117 are without significant modifications applicable only in a very limited range (e.g. application of M-701 engine for rail switch and other communication de-freezing). Their application in energetics or in transport requires significant design modifications, which are cost ineffective with regard to the costs relating with ATCE reconstruction to an alternative application as well as from a point of view of their residual technical life of these engines. A similar situation is also for aviation by-pass turbojet engine AI-25TL, AI-25, RD-33, D-30KU-154, having a small flux rate and their features are similar as for ATJE.

The greatest potential for ATCE transformation for an alternative application is seen for ATPE and helicopter ATSE engines, in which the power of the output shaft can be transmitted either directly or through a reducer to a driven aggregate (an electric generator, a compressor, a pump, a driving axle etc.). Such engines can be applied to drive the electric generator as a back-up or an emergency source of electric energy, for a power drive of compressors or pumps in solving crisis situations after disasters or in blackouts of electric energy etc. ATPE and helicopter ATSE, which are available from military aerial vehicles being cancelled (An-24, An-26 and L-410) and helicopters (Mi-2 and Mi-24) on the territory of the Slovak Republic provide a wide range of power on an output shaft from 294,4 kW up to 2075 kW at a weight from 139 kg up to 600 kg [5, 14, 16].

Basic parameters of ATPE and ATSE, being available on the territory of the Slovak Republic are shown in the Tab. 2.

Table 2 Basic parameters of ATPE and ATSE being used in SR Armed Forces Air Force

Ser.	Engine type	P [kW]	G [kg]	L [mm]	W/V [mm]	n_{FT}, max. [min.$^{-1}$]	n_{TC}, max. [min.$^{-1}$]	c_m [kg.W^{-1}.h^{-1}]	Remark
1.	**AI-24, 2. series**	1 887	600	2 346	677/1075	15 800	-	0,324	ATPE
2.	**AI-24VT**	2 103	600	2 346	677/1075	15 800	-	0,256	ATPE
3.	**M-601**	559	187	1 675	592/600	36 660	31 023	0,368	ATPE
4.	**TV2-117A**	1 104	330	2 835	547/745	21 200	12 000	0,4	ATSE
5.	**TV3-117**	1 636	285	2 055	650/728	19 500	15 000	0,313	ATSE
6.	**GTD-350**	294,4	139	1 385	626/760	45 000	24 000	0,486	ATSE

P – power; G – dry weight; L – length; W – width; V – height; n_{FT}, max. – maximal revolutions of a free gas turbine; n_{TC}, max. – maximal revolutions of a turbo compressor; c_m – specific fuel consumption.

2. AVIATION TURBO-PROPELLER ENGINE AI-24

The Ivchenko AI-24 turboprop aircraft engine was designed and developed in the late-1950s by the Ivchenko design bureau and manufactured thereafter by Motor Sich. It was designed to power Antonov's successful An-24, An-26 and An-30 aircraft series. In 1958, based on the experience gained in the course of designing the AI-20 turboprop engine and using advanced methods of simulation, a scaled-down turboprop engine, AI-24, rated at 1900 kW was developed. The engine was specifically designed to power the Antonov An-24 passenger aircraft. True to the Soviet tradition, design was kept separate from serial production which was started in 1960. The turboprop engine along with many of the bureau's other designs were manufactured at Motor Sich which is also located in Zaporozhye.

Single-shaft turbo-propeller AI-24 engines, 2. series had provided the medium transport An-24 aircraft with power till a tragic crash at the Hungarian village of Hejce, after which the An-24 aircraft were decommissioned from the operation in range of the SR Air Force. The more powerful version of turbo-propeller AI-24VT engines provided the transport An-26 aircraft with power, whose operation comes to end within the SR Air Force when their technical life is finished. Nowadays 6 pcs of these engines are available. Nowadays, Slovak Army turboprop transport aircraft An-24 and An-26 aircrafts are getting to end of their life cycle. After that, lot of parts will be sold as spare parts or junk. So this theme is today very actual. It is important to find another opportunity for alternative purposes for main parts as engines, to preserve their rest value.

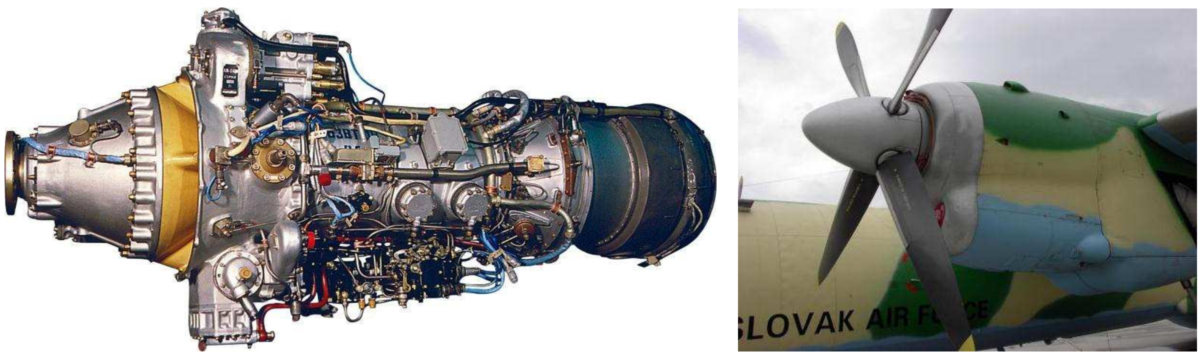

Figure 1 Turbo-propeller engine AI-24VT of the aircraft An-26 [5]

3. CONSTRUCTION AND SYSTEMS OF TURBO-PROPELLER ENGINE AI-24

AI-24 is single-spool turbo-propeller engine with a ten-stage axial compressor, annular combustion chamber, three-stage gas turbine and gas outlet system. Two engines AI-24 are the power unit of transport aircrafts An-24 and An-26.

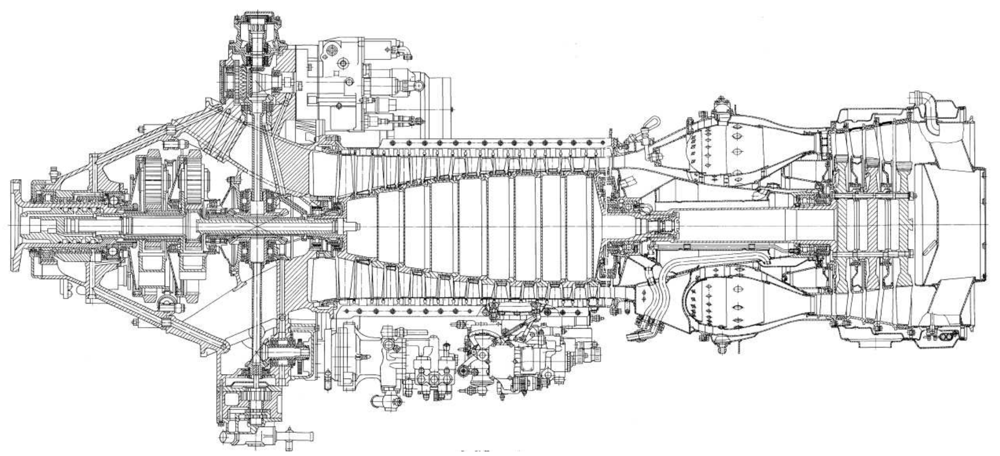

Figure 2 Cut way turbo-propeller engine Ivchenko AI-24 [10]

On engine are placed all necessary systems for operation: fuel system, fuel-engine regulation system, lubrication system, de-icing system and starting system. Each engine nacelle included a fire extinguishing system that could be set to an automatic operation mode. The AI-24 turboprop engines featured wide gas dynamic stability margin at all power conditions, altitudes and flight speeds. The most notable feature of the engine was in its operational reliability. The main advantages of the engine were simple design, high reliability, long service life and easy maintainability. The later AI-24T had water injection giving increased power output. It also introduced automatic limiting of power overloads and exhaust gas temperatures, along with vibration monitoring, automatic shutdown and feathering. [9, 10]

3.1. The Basic Technical Specifications of the turbo-propeller engine AI-24

Table 3 Basic technical specifications of the turbo-propeller engine AI-24

Engine power at take-off	$P_e = 1\,900$ kW
The maximum air flow at take-of	$Q_{air} = 14{,}8$ kg.s^{-1}
The maximum total degree of compression of the compressor	$\pi_{Ct,\,max.} = 9{,}55$
Specific fuel consumption at take-off	$c_m = 0{,}313$ kg.kW^{-1}.h^{-1}
The maximum total temperature after the gas turbine	$t_{Tt} = 750$ °C
The maximum speed of rotation the turbo-compressor	$n_{TC,\,max.} = 15\,800$ min.$^{-1}$
Total length of engine with aggregates and an outlet pipe	$L_{max.} = 2\,346$ mm
The maximum width of the engine	$W_{max.} = 677$ mm
The maximum height of engine	$H_{max.} = 1\,075$ mm
The maximum dry weight of the engine	$G_{max.} = 600$ kg

Table 4 Basic regime of the engine AI-24

Parameter / Regime	RPM of engine		Working time of engine τ [min.] (During technical life τ [%])
	n [min^{-1}]	**n [%]**	
Take of	15 100 ± 100	99,5 - 100,5	to 5 min. (to 3 %)
Maximal	15 100 ± 100	99,5 - 100,5	to 15 min. (to 3 %)
Nominal	15 100 ± 100	99,5 - 100,5	to 60 min. (to 25 %)
0,85 Nominal	15 100 ± 100	99,5 - 100,5	without boundaries
0,7 Nominal	15 100 ± 100	99,5 - 100,5	without boundaries
0,6 Nominal	15 100 ± 100	99,5 - 100,5	without boundaries
Idle (on ground)	14 050 ± 225	91 - 94	to 30 min. (without boundaries)

4. LEGISLATION OF CONSTRUCTION AND OPERATION OF ENERGY GAS TURBINES

Stationary power source must before putting into operation, to meet a number of legislative requirements concerning construction and ecology. Also manufacturer, supplier and the operator must demonstrate their competence to work in the energy sector and knowledge of the energy law, "The professional competence to conduct business in the energy sector". On the Slovak territory are valid regulations for environmental protection and standards of technical compliance. The main parameter for control of such devices is the amount of emissions that are released into the atmosphere. Then there are rules to protect against noise, explosive environment, working environment and ISO standards in terms of design.

Overview of standards and regulations:

- ISO 3977 - is an international standard related to the design and procurement of gas turbine system applications.
- ISO/DIS 19859.2 - Gas turbine applications - Requirements for power generation.
- ISO 21789:2009 - Standard for safety of gas turbine operation.
- no. 272/1994 - Slovak republic regulation for noise.
- no. 355/2007 - regulation of Slovak republic - „on protection, support and development of public health and amending some laws ".
- no. 393/2006 - The minimum requirements for occupational health and safety at work in explosive atmospheres
- no. 410/2012 - Slovak republic regulation for emissions. In Slovakia emission limits are about 20 % more strict than EU. There are no emission limits for emergency or back up source of energy.

5. ANALYSIS OF ACTUAL STATE OF ENGINE

Every machine by time or by work loses its original characteristics. We are talking about depreciation and for aircraft engine is no different. At present engineering as well as aviation is time to follow the trend of individual components work and maintenance plans before the damage and thus prevent work incapacity entire machine, or even damaged. It saves time and costs. But this method does not tell us about how it was straining engines, and in what environment worked. The engine can operate under minimum load, for example when doing routine military exercise, or high-performance when the transporting load oh hoist. Environment is also reflected in the condition of the engine. If the engine is operated in dusty environment, it should sanded compressor blades. In coastal areas, is high the risk of corrosion caused by moisture from the aggressive sea. It must not be forgotten that the level of maintenance is not the same everywhere and the ability of maintenance personal is reflected in the condition of the engine. All this has a significant impact not only on performance but mainly on the residual life of the entire engine. Therefore, when selecting or estimating the life of the engine it is necessary to do an analysis of the actual state of the engine.

By analysing the actual state we should be able to tell what state is the engine and an appraisal life. Also based on the results of the analysis can further determine whether the motor used or not, or replace some modules or modify the operating mode.

Process analysis of the actual state of the motor is convenient to divide into specific number of steps to introduce systematic and eliminate the possible oversights relevant facts or deficiencies, which could have ultimately consequences, especially financial. The process of analysis of the actual state of the engine should be performed by a person who has experience with a particular engine. Analysis procedure should be divided into the following sections:

- analysis of the documentation of motors;
- check the main parts of the engine;
- check engine systems;
- engine test;

- final report.

6. ANALYSIS OF THE ENGINE AI-24 FOR ENERGY USE

When designing the engine AI-24 for energy use, it is necessary to take into account all the characteristics resulting from the construction of the aviation turbo-propeller engine. The engine itself AI-24 is designed so that it can be almost without affecting the construction of the main elements be used for energy use.

By adjusting for the energy use can be understood any modification of the engine, which is used to produce electricity, the compressor drive source or mechanical work.

For gas compressor station AI-24 has low power. Nowadays are in gas industry used 30MW aero derivate engines and stronger.

For emergency use AI-24 has long starting procedure as almost every gas turbine engine. For these purposes are used diesel generators.

Use as short-term energy source is the principle area where the modified engine AI-24 has greatest ambitions. Back-up source of energy can be counted in the factories in order to avoid interruption of an important process, stadiums and computer centres, etc. A perspective area for the deployment of an engine could be backup source in the time of maximum electricity consumption. Then it is also the highest price of energy which would ensure the profitability of the project.

While the gas turbine excels in certain parameters, in practice, piston engines are preferred for the source of energy as mobile so static version. This is due to easier operation and reduced sensitivity to errors in operation. The price of new combustion turbine is extremely high. If it is already applied for such purposes combustion turbine is mostly adapted old aircraft engine.

6.1 Framework Design of Back-up Source Based on Engine AI-24

According to the analysis, engine AI-24 is suitable as a backup source of electric energy. It was suggest whole power unit for mobile, backup source of electric energy**Chyba! Nenašiel sa žiaden zdroj odkazov.**. There are demonstrating all important parts. Engine AI-24 after its removal from the aircraft does not require any major modifications of main parts of the engine. It can be used such as. Design consists of suggestion of generator, gearbox, placement, couplings, container and steel frame. For conversion from mechanical work of engine to electric energy is used 4-pole generator P7 firm Stamford.

Figure 3 Generator P7 firm Stamford [11]

It needs planetary gearbox which provides reduction of operating speeds and coaxial placement of all parts. Then next part which has to be designed is engine mounts.

Figure 4 Gearbox Renk CPG [12]

It has to be strong and tough to prevent resonance. Whole unit would be stored in classic 12 m long container for easy work with whole device. In the coat of container would be placed doors for easy manipulating with all parts. Shaft of compressor is fixed with gearbox. It provides freedom in setting position of engine by adjustable bars. Gearbox is connected with alternator by flexible coupling. Recommended is flexible coupling Flexiacer BSA.

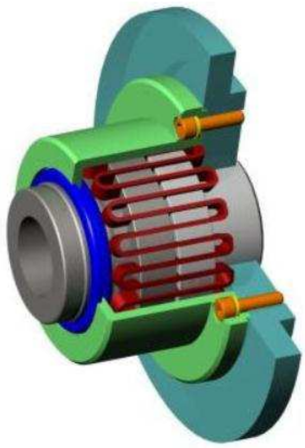

Figure 5 Flexible coupling Flexiacer BSA [13]

Container is divided in 2 rooms, engine room and control room. All rooms are separated by safety walls.

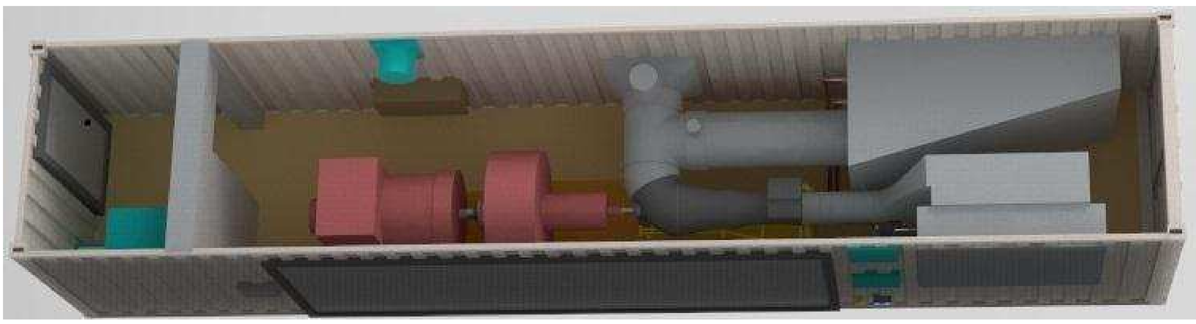

Figure 6 The location of the engine in a container

6.2 Modification of Main Systems of AI-24

When designing the engine modifications AI-24 for energy use it is necessary to adjust the engine systems. It is necessary to modify the fuel system, oil system, starting system. On the engine is installed low-pressure fuel system, the basic fuel circuit, the limit system for the engine operation modes, the limit system for the temperature of the gas turbine compressor, drainage systems and piping.

When modifying is only necessary to connect the fuel line from the tank to a delivery centrifugal fuel pump BNK low-pressure system, which is placed on the engine drive rack. For safety reasons it is best to separate the tank from the engine compartment. It is proposed the use of 16 000 l Benkalor. The tank should provide engine running for 30 hours. By the tank is placed delivery pump with filter, flow meter and shut-off valve. Tank itself is equipped with the air vent valve and drain valves. Fuel hose connects the tank to the engine via connections to a static fuel tanks and containers with energy unit.

In the container of the power unit is between the external connector and the pump BNK placed fire valve, controlled either automatically by fire protection system or manually.

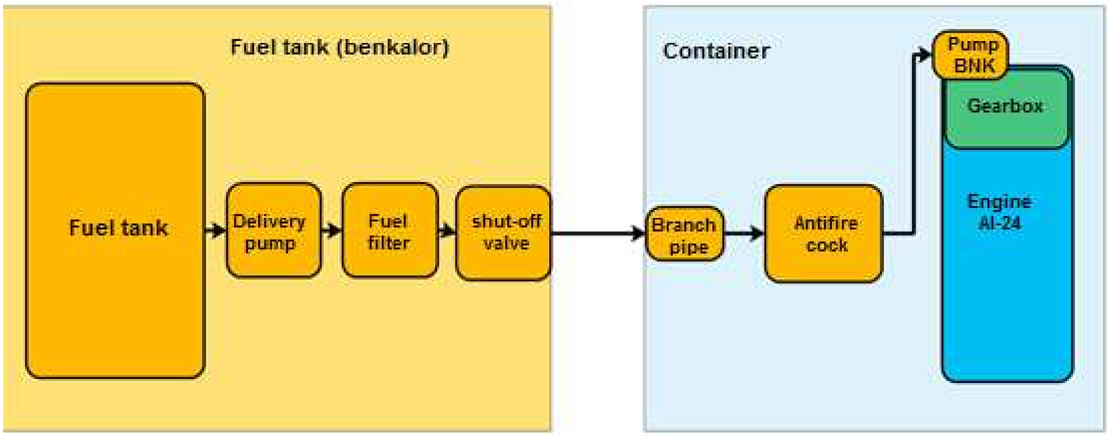

Figure 7 The fuel system of the engine

Proposal lubrication system for energy use can also seek a modification. The entire lubrication system except cooler is installed on the motor. Cooler would be placed in entry of the engine.

For starting the engine AI-24 is used starter-generator STG – 18TkO – 1000 supplied by electricity from 2 batteries.

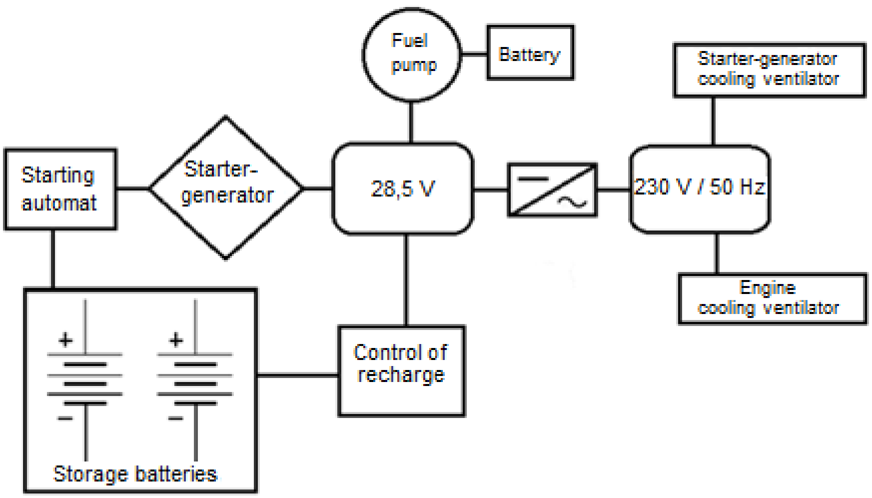

Figure 8 The electric scheme of the starting system

On the safety and reliability of the engine has a significant impact frost, which occurs under specific atmospheric conditions. The greatest risk of icing is at a temperature from 0 °C to 4 °C at high humidity. Icing may significantly affect the operation of the engine, or in the worst case, cause damage. It is therefore essential to ensure the optimum temperature of the intake air to the compressor (5 °C). Active anti-icing system reduces engine efficiency. Therefore, in the framework design of the energy use is used heat exchanger, which ensures the heated air is at the inlet to the compressor at optimal temperature. To heat the air used off-gas heat. System is triggered only in specific weather conditions.

7. CONCLUSION

The current situation in the world is full of military conflicts and natural disasters. It requires having strong and mobile backup power source.

Analysis of the possibilities of the engine AI-24 for energy use concluded that the engine is suitable as a backup power source, either static or mobile. Aircraft engines have a high ratio of performance to weight, and that's the main parameter for mobile version. While in industry in power category to 2 MW diesel generators become established, but compared with transformed retired aircraft engines operation is more expensive and harder.

When designing the engine modifications AI-24 for energy purposes must comply with the regulations applicable to such facilities, so the work has produced legislation requires modifications to the land use of aircraft engines. There are mentioned and described rules concerning gas turbines for energy use.

Using appropriate turbo-propeller engines available after its service life reduce the price of device for the production of electricity. However, before using engine, it is necessary to carry out an analysis of the actual state of the engine. Thus avoiding unnecessary waste of financial resources to destroyed engine or prevent engine damage due to easily removable problems, but the lack of an unknown engine. Analysis of the actual state is an important process that must be made responsible and experienced person.

Changes connected with grounding motor AI-24 are not demanding and are feasible even without the participation of the manufacturer. Framework proposal describes the adjustment of the engine parts and adjust the fuel, lubricating, release and defrosting system. Part of the de-icing system is a heat exchanger, a draft of which must be disposed of discussions. To better understand the processes in the engine AI-24 was processed to calculate the thermal circulation for the first Cruise mode. However, for a deeper understanding of the work and the conditions the engine is necessary to obtain all the characteristics of the engine.

Use of redundant and decommissioned military equipment is not only an economic and ecological point of view effectively, but also will benefit in the future. It is therefore necessary to continue developing the issue of conversion of aircraft engines for energy use.

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