Status and prospects for helicopter APUs in Russia

Gavrilov V.V. , Ponomarev B.A.

Introduction

Auxiliary gas turbine power units (APU) represent a special class of engines designated for being used on flying vehicles of different purpose. APUs are applied for starting cruise engines, power supply, and flying vehicles conditioning during preflight maintenance and often in flight (under both standard and emergency conditions).

Developers and operators of flying vehicles specify high requirements to the modern APUs in respect of safety, reliability, bleed air parameters, life, high controllability, low cost of acquisition and ownership. APUs should have low specific fuel consumption, low weight and small size, low noise and emission level. The specific requirement to APUs , taking account of their size , is set to their ability to start and operate at high flight altitudes – up to H= 11 – 12 km (for aircraft APUs) and, in some cases, even above them.

In accordance with the technical level standards (TLS) all APUs fall into 4 standard sizes depending on the value of available equivalent power that is determined by parameters of bleed air and electric power:
standard size 1 – Ne = 75 kW; standard size 2 – Ne = 250 kW; standard size 3 - Ne =450 kW; standard size 4 – Ne = 700 kW.

The modern Russian helicopters mainly use the APUs of standard size 1 (the AI-9 and its derivatives) and seldom the engines of standard size 2 (the TA8 on the Mi-26 and Ka-31 helicopters).

Production APUs

Nowadays in spite of significant range of helicopters in the Russian Federation, the needs of APUs are satisfied practically by one production engine – the AI-9 (Ne ≈ 50kW) that is produced in different versions. This engine is now foreign and in some cases it is a home engine – TA-8 (Ne = 130 kW). Both these APUs were developed in the sixties – eighties and are engines of the first generation. Their parameters are given in table 1.

The AI-9 and AI-9V (Fig.1) are installed on helicopters together with the TV3-117 engines, and as the most of the APUs of this class are single-shaft engines with a common compressor; they include a single-stage centrifugal compressor, an annular reverse-flow combustor and a single-stage axial turbine. The AI-9 enables to bleed as much air as 0.38 kg/s at pressure 2.4 kg/cm^2 and temperature 130°C. The AI-9V engine enables to bleed 0.4 kg/s air at pressure 2.9 kg/cm^2 and temperature 160°C , and to take-off 3 kVA dc electric power (electric power and air are not bled simultaneously).

The AI-9 allows to carry out threefold air bleed for cruise engines starting over a cycle of up to 13 minutes, and the AI-9V – three bleeds over a cycle of up to 10 min. Besides, the AI-9V admits up to 3 kW electric power take-off during 30 min. So, both engines are rather limited functionally in respect of continuous operation time.

The AI-9 weight as a package is 45 kg, its overall dimensions are 740x 515x 490 mm. The AI-9V weight is 70 kg, its dimensions are 888 x530 x490 mm. Starting and operating altitude tolerance for both engines is 4,000 m.

It should be noticed that in terms of technical level both engines (developed in the sixties) compare unfavourably with the modern foreign engines of the same power class. Due to lower rotor speed as well as lower specific work of the turbocompressor the AI-9 and AI-9V are made heavier than the best foreign engines.

Even in comparison with “Saphir-5M” APU (Czech Republic) the AI-9 gas generator is by 5-7 kg heavier. The AI-9 and AI-9V engines are designed without taking account of the requirements specified at present for APUs by APU airworthiness regulations (APUAR). That is why it is necessary to carry out the special analysis and additional tests to confirm their safe operation.

At present ZMKB “Progress”, the developer enterprise, has created a more powerful derivative of the AI-9 engine – AI9-3B (see table 1 for parameters) designated mainly for the An-10 aircraft powered by the TV3- 117SB3 engines.

Fig.2 shows the TA8 APU – a serial engine produced in two versions – the TA8 and TA-8K (“K” – for the Ka-31 helicopters). Its total equivalent power is 128 kW with the following bleed parameters: G_{bl} =0.8 kg/s , P_{bl} =3.4 kg/cm^2, N_{el}= 10 kVA (25 kVA without air bleed). This APU’s life is 2,000 h / 8,000starts.

Now the developers of these APUs are taking measures aimed at their upgrade including extension of the specified life and improvement of the ecological (noise and emission) , operational, reliability and failure-free operation characteristics. Upgrading these engines as well as extension of their life will shorten their required number and will enable to cut operational costs.

But upgrading cannot rectify such significant drawbacks (for example, those of the AI-9) as impossibility of simultaneous provision of compressed air for conditioning and electric supply as well as limited time of operation (not longer than 20 – 30 min). And that is of prime importance for a number of helicopter applications, such as a hospital helicopter, a command post helicopter, a VIP (presidential) helicopter, which demand continuous electric power and compressed air supply during several hours. In this connection the home developers often have to orient themselves to foreign APUs, such as "Saphir", for example.

Second generation APUs

The development of the second generation APUs designated for the fleet of flying vehicles of 1990 – 2000 was started in Russia at the beginning of the nineties. However almost all the developments were stopped for economical reasons. Nowadays of these APUs the TA14 engine (Ne= 110 kW, standard size 1) has been developed by OAO NPP "Aerosila". Since 1999 this enterprise has been working on a project of a new APU of standard size 2 with Ne =285 kW . It was designated as the TA-18-100. The experimental bureau of motors in Kaluga (KEMB) has also developed the VGTD-2 – standard size 2 engine with Ne = 256 kW. But both these APUs appear to be oversized for their application, even for such a heavy helicopter as is the Mi-26 or its versions. The information on new APUs is given in table 1.

The TA-14 APU (Fig.3) is designed for replacement of the AI-9 and is capable to provide compressed air bleed of 0.55 kg/s at P_{bl}=3.7 kg/cm^2 or electric power take-off of order of 20 kVA; simultaneous air bleed is possible at electrical load up to 10 kVA. Besides, this APU has a mechanical power take-off shaft for hydropump drive for the object needs on ground (up to 3 kW). The TA-14 has a configuration with a common compressor and is equipped with the present-day single-channel FADEC without a hydromechanical back-up. The specific indices are in compliance with the technical level standards (TLS) 2000. The TA-14 compares favourably with the AI-9 in terms of all the technical parameters. At present the TA-14 is undergoing the development and certification tests. The tests carried out in CIAM's thermal vacuum chamber (TVC) and aimed at verifying starting reliability, performance measuring as well as antiicing system operation check have completed successfully. The certification tests with a view to meet the APUAR requirements are expected to complete in 2001.

The TA-18-100 (Fig.4) is a standard size 2 engine with Ne up to 285 kW, bleed air amount 1.27 kg/s at pressure 4.52 kg/cm^2 and ac electric power take-off up to 60 kVA . This APU is designated for the Tu-334 and Be-200 aircraft which are temporarily powered by the TA-12-60 aged engines. The TA-18-100, like the TA-14, has the configuration with air bleed behind the compressor and, in fact, is a scaled version of the TA-14. The engine weight without alternator is 140 kg, its specific fuel consumption is 0.53 kg/kW.h, starting and operation altitude tolerance – 11,000 m, design life – not shorter than 12,000 h. At present in respect to this engine the working design documentation has been issued, the technological preparation for production has been made, and manufacturing of the prototypes has started. Later on in 2001 – 2002 a set of developmental and certification tests should be carried out, and a type certificate is planned to be obtained in 2002.

The VGTD-2 (Fig.5) developed by KEMB with the same air bleed parameters as those for the TA-18-100 unlike the latter is made with a service compressor that has a variable IGV. Because of the additional compressor the VGTD-2 has somewhat worse performance in comparison with the TA-18-100 (see table *2*). But using an APU of such a scheme it is possible, in principle, to obtain a better fuel efficiency as the choice of π^*_c in the gas generator compressor is not limited by value of bleed air pressure; besides, it is possible to redistribute the electric generator and service compressor load more flexibly.

The analysis of the second generation engines shows that in terms of specific parameters these engines are much better than the production ones. So, in comparison with the TA-6A in the same power class the TA-18-100 has the improved by ~43% C_{sp} and by ~76% γ. Such improvements of the TA-18-100 specific indices (in comparison with the TA-6) has been obtained mainly due to the increase of the turbomachines efficiency as well as owing to the rise of turbine inlet temperature by 100 - 120° up to 1,130K at almost equal π_c^* =4.7 – 4.8. It should be noted that η_c^* is increased at design point from 0.72 up to 0.805, and η_t^* - from 0.825 up to 0.864. The weight reduction of the new APUs of standard size 2 is achieved owing to substantial decrease of compressor and turbine stage number. Thus, the TA-18-100 compressor is single-staged instead of a three-stage compressor in the TA-6A, and its turbine is a single-stage radial component in comparison with the TA-6A three-stage axial turbine. Besides, the new APUs rotor speed is also increased. The simple design of the TA-14 and TA-18-100 engines, that is such due to their configuration with the common compressor at specified modest parameters of the operating cycle, allows to expect the high structural reliability and low costs of production and on-condition service maintenance. At the same time, the TT requirements are met in respect to air bleed parameters and performance, mass-dimensional indices, fuel consumption.

Comparison of home-made and foreign APUs technical level

Fig.5 demonstrates the specific indices of the production APUs applied in home aviation versus their equivalent power (standard size). The helicopter APUs take the extreme left area on the plots. Fig.5 also shows the data of foreign production APUs . The analysis of the data and comparison of the home-made and foreign APUs gives the following:

1.Home-made production APUs (of the 1st generation) including those for helicopters compare unfavourably with the foreign ones in terms of fuel efficiency (by 25 – 30%) and specific mass (by 30 – 40%). In respect to life, reliability and safety indices they are also at disadvantage (by 30 – 50%) in relation to the foreign analogs. On-condition service operation is not used for home APUs (as it is in the case of foreign ones) because it demands them to be equipped with the comprehensive diagnostic system that so far is not applied in home APUs. The home APUs serviceability is either not so good as that of foreign ones.

2.The second generation APUs (the TA-14,TA-18-100, VGTD-2) are in line with the production foreign engines in terms of specific indices and comply with the TLS 2000.The life levels specified for the 2nd generation home APUs are also in compliance with those of foreign engines, but to achieve them it is necessary to use the principles of APU life design in development work. To make home APUs capable to compete with the next generation foreign engines it is necessary to take measures in order to be able to improve their performance in future.

Below there is given some information about work of CIAM.

Work carried out in CIAM and forecast for the period up to 2010 – 2020

In 1999 – 2000 in accordance with the “ Federal program of aeronautical engineering development up to 2015” CIAM carried the 1^{st} stage investigations on further improvement of home APUs and development of the configuration for the 3^{rd} generation APUs which are designated for application on flying vehicles of 2015 – 2020 and should be high-effective engines that could compete with the similar foreign APUs. The investigations carried out have shown that the advanced helicopter APUs (standard size 1, Ne ≈ 100 – 120 kW) should still have the configuration with the common compressor and have π^*_c =4 –5 , T_g^* = 1,200 – 1,250K. On the basis of such a level of cycle parameters (without turbine blades cooling) the fuel efficiency is expected to be improved to 0.5 – 0.55 kg/kW.h. The resulting low increase of fuel efficiency – by 7 – 10 % in comparison with the TLS 2000, according to calculation, is accompanied by 30% increase in specific power that will enable to improve mass-dimensional indices of APUs. To reduce weight of the advanced APUs it is necessary in their development not only to use new technological and design techniques and materials but to take measures aimed at decreasing weight of the mounted on them assemblies by 20 –25%. The weight of assemblies mounted on current APUs including the control system reaches 30 – 40%.

Besides the work on ensuring higher specific indices (in respect to fuel efficiency, weight and overall dimensions)for the advanced APUs it is necessary to take measures for improving their operational characteristics in order to reach by 2011 – 2020 : the hot part life of order of 8,000 h/10,000 cycles (starts) and the cold part life – 16,000 h/ 20,000 cycles; labor content in maintenance – 0.1 – 0.2 hour/ flight hour; starting/operation altitude tolerance – 5- 6 km. The noise level of

APUs should be in compliance with ICAO standards and below; level of NOx emission should be 6 –15 g/kg of fuel, Cx Hy – 0.5 – 2 g/ kg of fuel, soot ≤ 50 units (recommended values).

In conclusion it should be noted that performed by CIAM analysis of the requirements specified to APUs by helicopter developers and operators has shown that the TA-14 APU under development seems to be oversized for application on helicopters and is more suitable for use on light passenger aeroplanes, such as the Il-114. In this connection it seems reasonable to consider the question concerning the expediency of developing for helicopters specially the APUs and power plants of so called standard size 0 with Ne ≈ 50 kW.

Conclusions

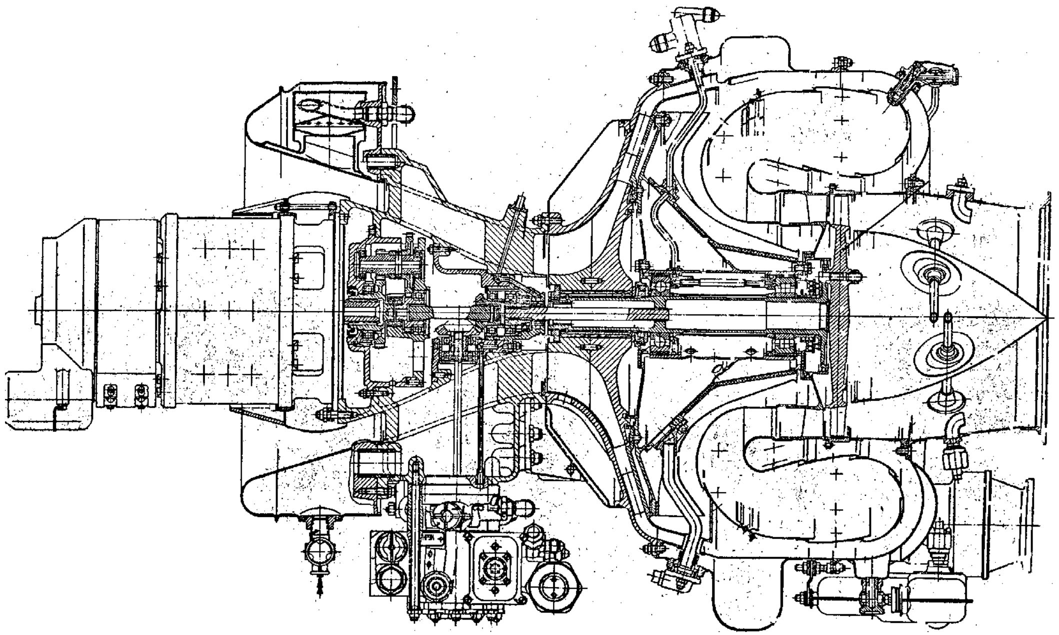
1. The production helicopter APUs that are now in service operation compare unfavourably with the foreign engines in terms of fuel efficiency (by 25 –30%) and specific mass (by 30 – 40%). They are also worse in respect to other indices. The measures being taken now are mainly aimed at improvement of these APUs life and reliability characteristics.
2. The second generation TA-14, TA-18-100 and VGTD-2 that at present are under development at OAO "Aerosila" and KEBM are in line with modern foreign production ASPUs in respect to their specific parameters. The investigations carried out show the expediency of their further improvement in order to raise their competitiveness on the world market.
3. Performed by CIAM analysis of the requirements to APUs by helicopter companies shows that it is necessary to consider the question about the expediency of developing specially for helicopters the APUs and power plants of so called standard size 0 with $N_e \leq 50$ kW.

PARAMETERS OF HOME-MADE HELICOPTER APUs

№	APU	N air, (kW)	M , kg	LxWxH mm	Gf, kg/h	P bl, kg / cm^2	G bl, kg/s	T*bl,° C	Life, h/st.	H st H oper, m	Status
1	AI-9	~	45	740 515 490	75	2.4	0.38	130	-	4,000 4,000	Production
2	AI-9B	~ 46 3 kVA	70	888 530 490	80	2,9	0.4	160	170 1,000	4,000 4,000	Production
3	AI9-3B	~ 78 16 shaft	112	1,149 531 663	100	4.7	0.47	190	600 1,250	6,000 6,000	Production
4	TA-8	128 10 el (25 without air bleed)	185	1,370 700 705	130	3.4	0.8	210	2,000 8,000	5,000 5,000	Production
5	TA14/100	108 20 kVA	55	835 507 440	73	3.7	0.55	190	4,000 12,000	8,000 9,000	Prototype
6	TA18-100	262 35 kVA 60 kVA	156	1,100 690 714	140	4.52	1.27	200	12,000 -	11,000 11,000	Prototype
7	VGTD-2	256 60 kVA	169	1,580 700 630	130	4.37 start 3.5 long-duration bleed	1.22 0.56	212	12,000 14,400	10,000 10,000	Prototype

AI-9V APU

(Mi-24, Mi-28, Mi-17, Ка-28, Ка-50, Ка-60, Ка-62)



MAIN PARAMETERS

Ne = 46 kW,   **Csp.** =1.74 kg/kW.h

γ = 1.52 kg/kW.h

Overall dimensions = 888 x 530 x 490

Life= 170 h / 1000 starts

BLEED PARAMETER

G bl. = 0.4 kg/s

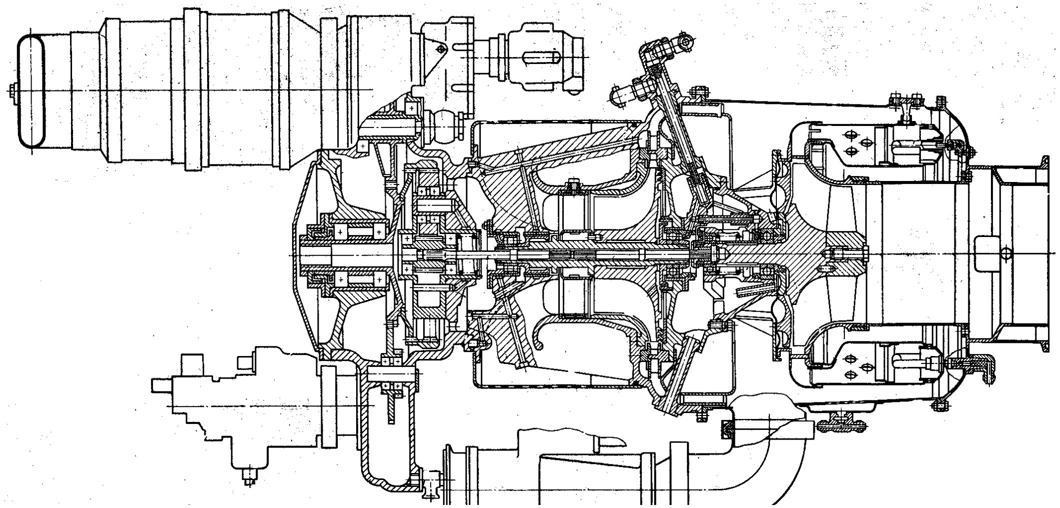
Pbl = 2.9 kg/cm^2

T bl air = 160°C

Nel. = 3 kVAт

Fig.1

TA-8 APU UPGRADING
(Mi-26, Кa-31,Tu-134A,M)



MAIN PARAMETERS

Ne = 128 kW, **Csp** = 1.09 kg/kW.h

γ = 1.44 kg/kW(without alternator)

H = 5,000 m

Life= 2,000 h / 8,000 starts

Overall dimensions 705 x 700 x 1370 mm

BLEED PARAMETERS

Gbl = **0.8 kg/s** Nel. = **10 kVA**

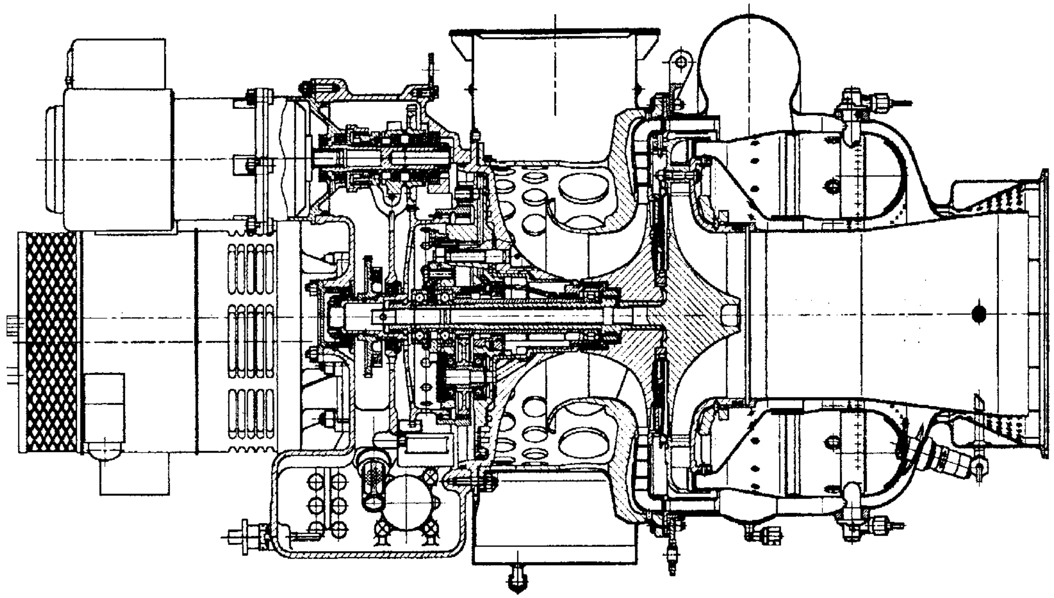
Pbl = 3.4 kg/cm^2 **Nel** = 25 kVA (without air bleed)

Tbl = 210 °C

Fig .2

TA-14/100 APU

(Tu -114, Tu-324, S-80, Кa-27, Кa-50,Mi-8MT, Mi-17)



MAIN PARANETERS

Ne = 108 kW, **Csp.** = 0.675 kg/kW..h

γ = 0.479 kg/kW (without alter.)

Life = 12,000 h/ 15,000 starts

Dimensions = 835x507x440 mm

H = 8,000 – 9,000 m

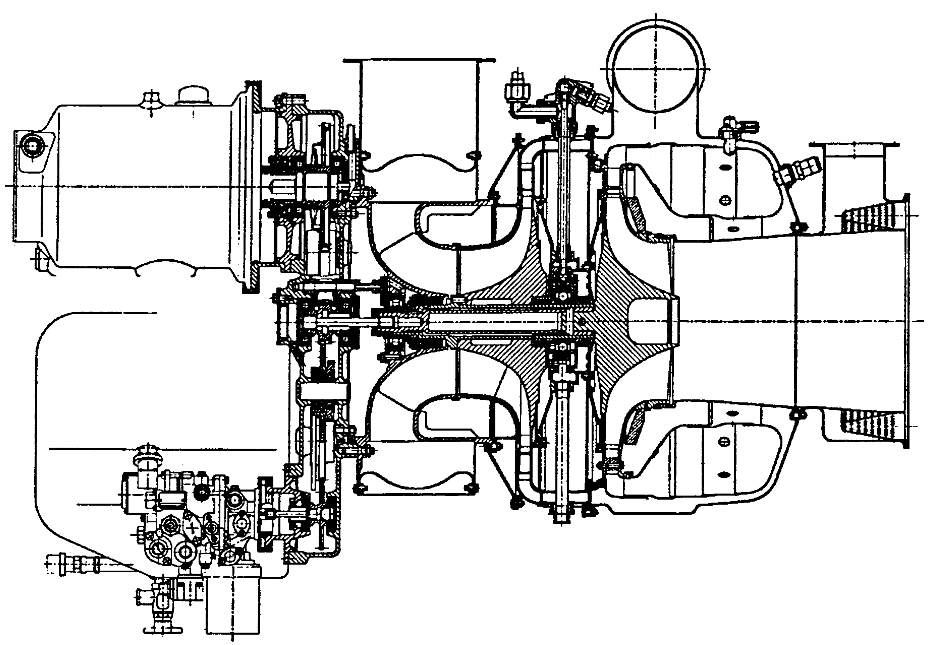
Bleed Parameters

Gbl = 0.55 kg/s , **Pbl** = 3.7 kg/cm^2

Nel. $\leq$ 20 kVA

Fig .3

TA-18-100 APU



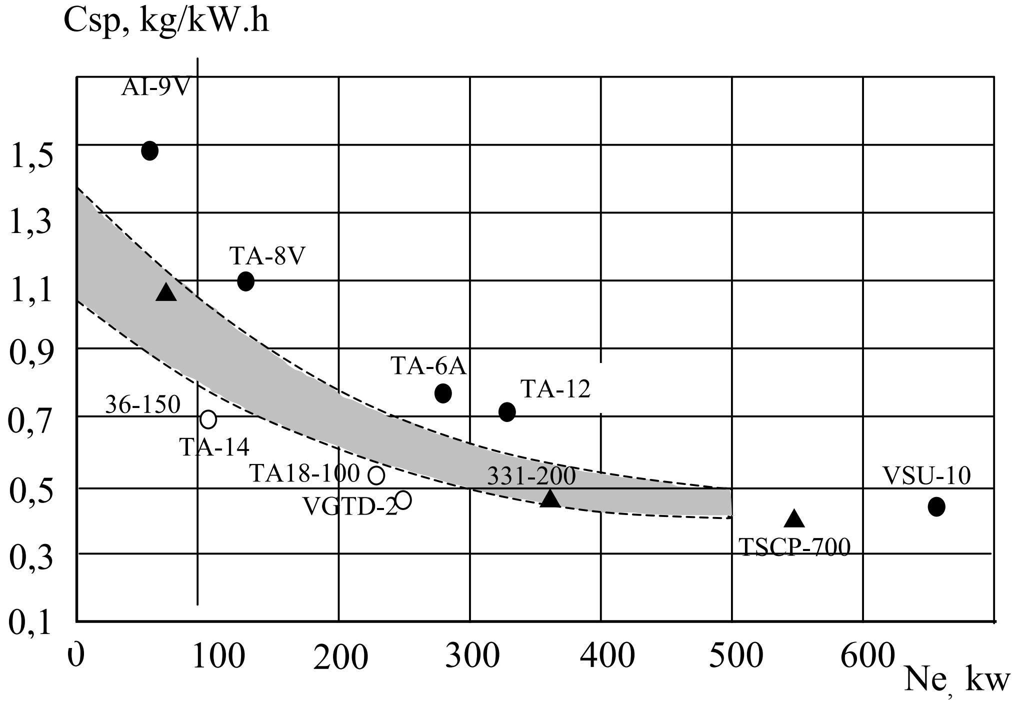
MAIN PARAMETERS

Ne = 262 kW (at Nel=35 kVA simullt.)
Csp = 0.53 kg/kW
γ = 0.595 kg/ kW (withot alter.)
Dimensions : 1100 x 690 x 714
Secified life:-12,000 h /15,000 starts
Initial life.-1,000 h /2,000 starts
H st /oper = 11,000 m

BLEED PARAMETERS

Gbl = 1.27-1.35 kg/s
Pbl = 4.52 kg/cm^2
T bl= 210 ^{o} C (**N air** = 227 kW)
Nel. = 60 kVA

Fig 4



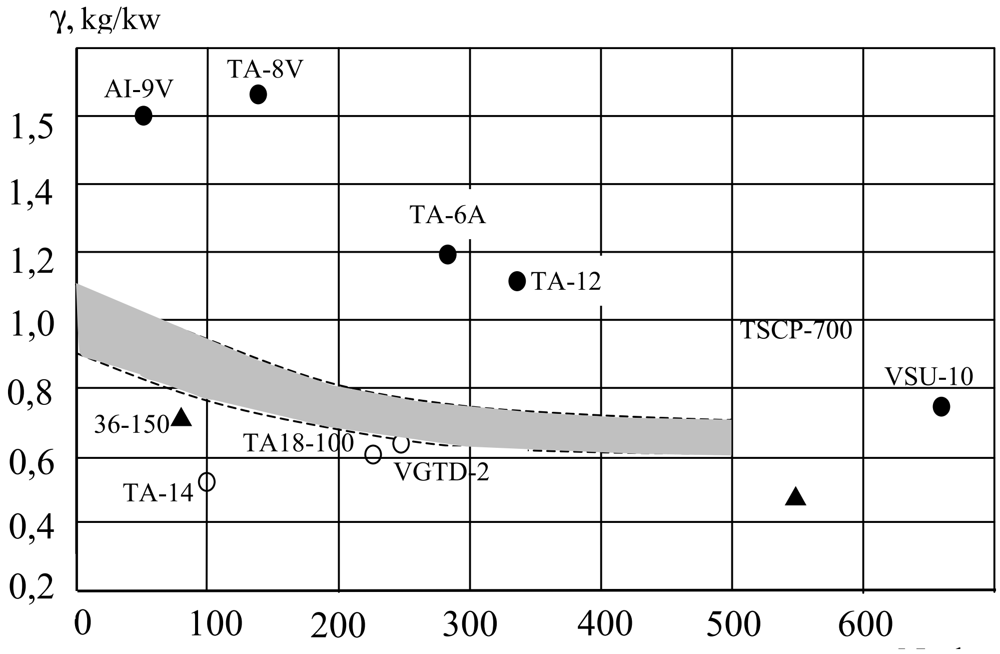


Fig .5 Specific parameters of production APUs

● - production APUs ○- 2nd generations APUs ▲ - foreign APUs