MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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# DESIGN OF THREE-SPOOL TURBOFAN

Tutorial

Kharkiv “KhAI” 2022

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B44

Розглянуто конструкцію двигуна Д-36. Викладено загальні відомості про двигун і літальний апарат, на якому його застосовують. Описано конструкцію основних вузлів двигуна: вентилятора, компресорів низького і високого тиску, проміжного корпусу, камери згоряння, турбін високого і низького тиску, турбіни вентилятора, корпусу задньої опори, реактивного сопла.

Для англомовних студентів, які вивчають конструкції авіаційних двигунів та енергоустановок.

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The design of the D-36 engine was considered. General information about the engine and the aircraft on which it is used is presented. The construction of the main components of the engine is described: fan, low and high pressure compressors, intermediate housing, combustion chamber, high and low pressure turbines, fan turbine, rear support housing, jet nozzle.

For English-speaking students studying the design of aircraft engines and power plants.

Figs 47. Table 1. Bibliogr.: 3 names

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**CONTENT**

# 1 GENERAL INFORMATION ON ENGINE

Turbofan engine D-36 (Figure 1.1) is designed to be installed on passenger and cargo aircraft. Figure 1.2 shows the engine structurally-design scheme.

The engine is made under the three-shaft design scheme with a front fan location and shortened bypass; consists of an axial fourteen-stage compressor, the intermediate casing, an annular combustion chamber, a five- stage turbine and fixed nozzles (primary and secondary). Instead of the bypass nozzle the thrust reverser can be set on the engine.

The feature of three-shaft scheme is the separation of the compressor rotor into three independent rotors, each of which is driven by its turbine. In this case all rotors have a different optimal rotational speeds and are interconnected only gas-dynamically.

Using of engine three-shaft design:

- made compressor stages very efficient;
- provide the necessary compressor stability;
- use at a lower-power starter, as it must accelerate only the high pressure rotor.

The high bypass ratio ($m \approx 5.6$) and high parameters of the gas-dynamic cycle ensure engine high efficiency.

The basic units are beneath the engine, which makes it easy to access each of them.

*Single-stage fan* has no inlet guide vanes, and consists of the impeller, a stator followed by straightening vanes, shaft bearing assembly and a rotating spinner which is heated with air.

The fan disk connections to the drive shaft and to a spinner - are bolted, the blades are connected to the disk by the "dovetail" locks.

Fan blades have shroud anti-vibration shelves disposed in the bypass. Straightening vanes assembly is the non-detachable construction, with sound-absorbing panels.

The shaft of fan is connected to the fan turbine shaft with splines. Both fan rotor bearings are mounted on the oil dampers.

A *low pressure compressor* (LPC) consists of a front housing with inlet guide fixed and adjustable vanes, rotor, stator, air bypass valves and the bearing assembly.

The compressor rotor of drum-disk structure is connected to the front and rear shafts by means of bolts. Both the low-pressure rotor bearings are mounted on the oil dampers.

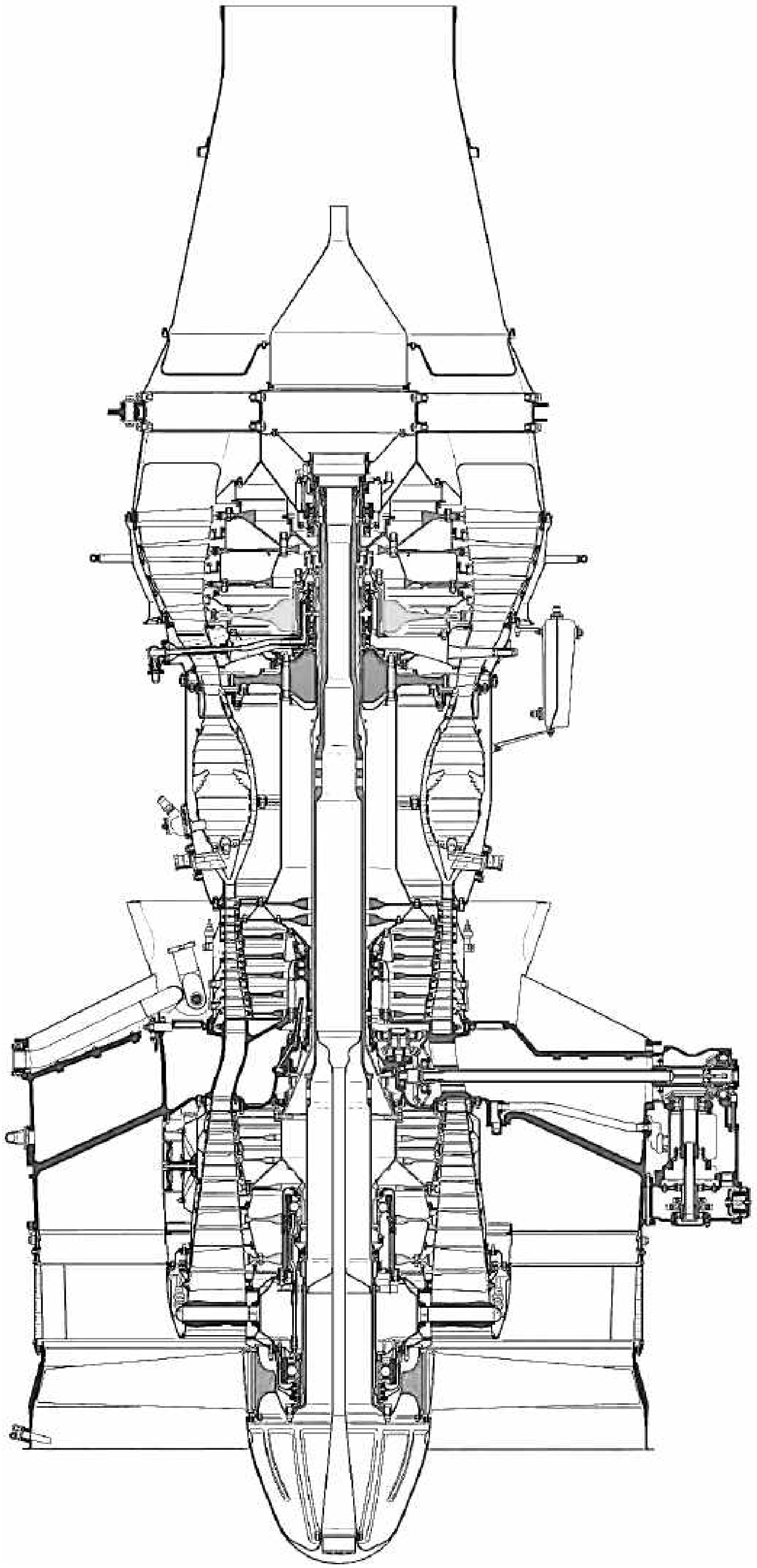

Figure 1.1 – Turbofan D-36

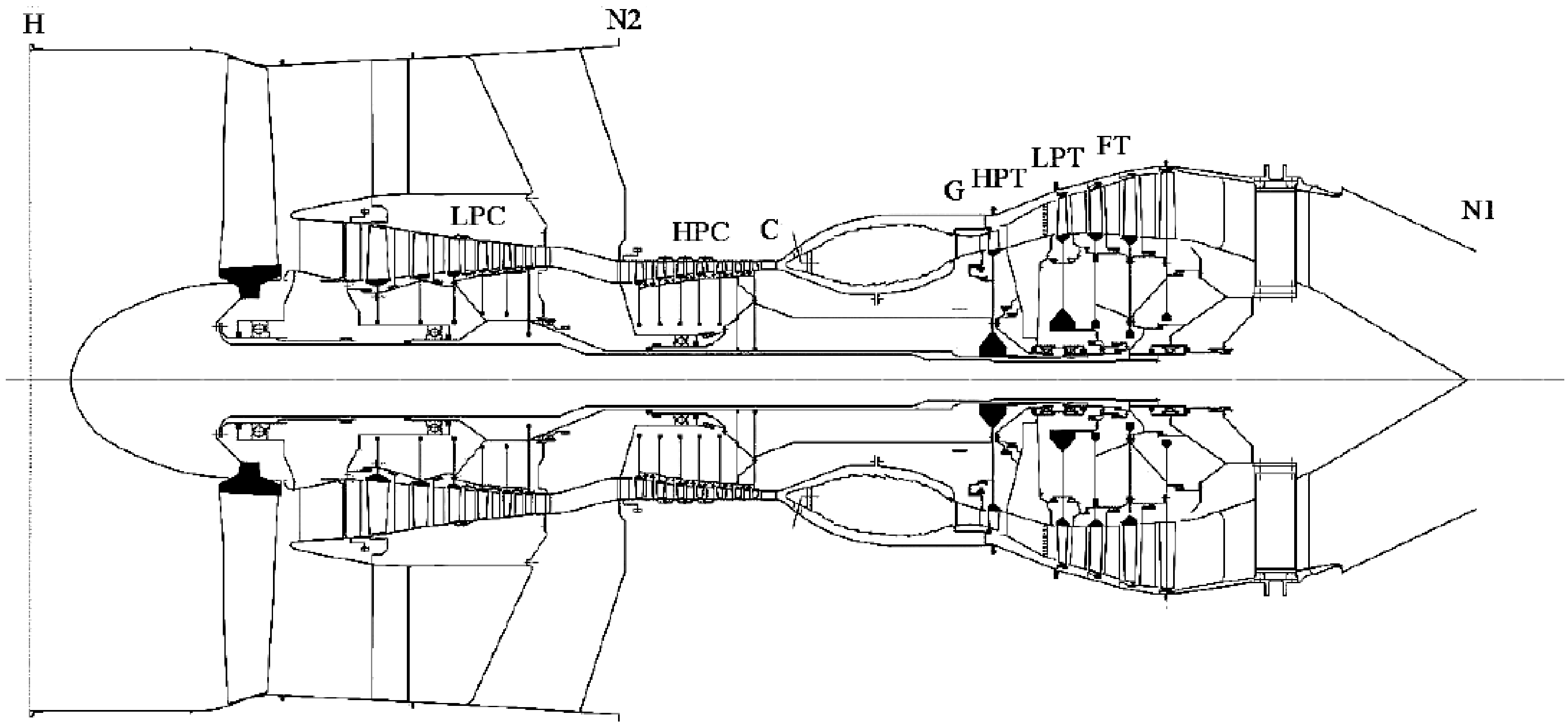


Figure 1.2 – Turbofan D-36 structurally-design scheme

Low pressure compressor stator with its fairing separates airflow downstream the fan impeller on the two flows - primary and secondary.

The presence of LPC adjustable inlet guide vanes allows debugging engine test-bench.

A compressor rotor is connected to the rotor of the turbine by means of splines.

*The high pressure compressor* (HPC) is composed of inlet guide vanes, rotor, stator, air bypass valves and bearing assembly.

The high pressure compressor rotor is of drum-disk structure. Welded drum, discs of the last stages, spacers and shafts are interconnected by bolts. HPC rear shaft connection with high-pressure turbine - also bolted.

Front ball bearing is mounted in the elastic support with hard stroke limiter. Rear roller bearing of high pressure rotor is installed on the oil damper.

HPC adjustable inlet guide vanes allow debugging at engine test-bench.

*The intermediate casing* is used for the formation of a transition path from the LPC to HPC and to the bypass, the placement of units and drives for them, as well as placement of the HPC front rotor support and front engine mount belt.

The annular shells forming the primary flow path and bypass are interconnected by eight hollow struts, in which communications are placed.

Intermediate casing consists of housing, a central drive box and drive column. All engine driven units are rotated by HPC rotor.

*The combustion chamber* consists of housing, the flame tube, the fuel manifold with spray nozzles and pilot burners. Flame tube is annular, with 24 spray nozzles.

Flame tube - welded construction, it consists of separate rings with a series of holes for the passage of the secondary air.

Working spray nozzles are centrifugal, single-channel.

*Turbine* is three-shaft, reactive. Single-stage turbines rotate compressors of high and low pressure, three-stage turbine rotates fan. The direction of rotation of all three rotors is anticlockwise.

*High pressure turbine* consists of an impeller and nozzle unit.

The nozzle unit is collected from the eight individual sectors. Each vane has a deflector for pressing of the cooling air to the inner walls of the vane.

High-pressure turbine disk is cooled; the rim has fir-tree grooves for installation of rotor blades.

Blades are cooled, consist of the root part, of the airfoil part and shroud place with crests. Cooling air is supplied to the root part; it passes through the radial channels in the body of the blade and flows through holes in the shroud shelf into the gas path.

At each disc groove 2 blades are set.

*The low pressure turbine* consists of a stator and rotor.

The stator includes supports housing of high and low pressure turbines, wherein the outer and inner shells are interconnected by spokes extending inside the hollow vanes of the turbine II stage nozzle unit. Also all housing communications are placed inside the vane.

The nozzle vanes, cast in the form of sectors on three vanes in the sector, are cooled, blades are uncooled.

The rotor blades are shrouded. The disk plate is cooled by air.

*The fan turbine* consists of a rotor and stator.

Fan turbine stator consists of housing and three nozzle units assembled from separate cast sectors of five vanes in the sector.

The turbine rotor is of the of drum-disk design. Disks are connected among themselves and with the fan turbine shaft with the bolts.

As nozzle vanes so blades are uncooled, fan turbine disks are cooled by air taken from an intermediate stage of the HPC.

The rotor blades are shrouded.

*The exhaust system* is designed to form an engine exhaust duct, placing the back support of the fan rotor and the rear engine mounting units.

*Rear engine mounting belt* is designed as a power ring with holes for connecting engine elements for mounting it on an airplane. This ring is a part of the back support housing outer shell. Inside the case is a bearing assembly of the fan rotor. In the struts (racks), connecting the inner and outer shell, communications of the fan rotor rear support are located.

*Engine oil system* is closed, circulatory, pressurized.

The oil supply to the lubrication system is carried out with pressurizing section of oil assembly. Four scavenge sections pump out oil from the oil cavity of the engine rotor bearings and from the drive box cavity (sump).

*Oil cooling* is produced in the fuel-oil unit (FOU), installed in the fuel low-pressure line between the boost and main fuel pumps.

*Venting oil cavities* of turbine supports is implemented through the separation chamber (vertical rack of the intermediate casing), where the pre-separation of oil occurs. Next to the emulsion of the turbines supports joins the emulsion of the compressors supports and jointly sent to the centrifugal breather from which the purified air is released into the jet engine nozzle. The air cavity of oil tank is breathed in the drive box, which is breathed directly through the venting centrifugal breather.

*Engine fuel system* supplies fuel to the engine in an amount determined by the position of the thrust lever and flight conditions.

*Fuel metering units* carry out: dispensing of fuel at start-up, pick-up and operating modes, control of LPC and HPC air bleed valves, engine temperature and overspeed protection.

*Engine startup* is implemented by air starter mounted on the engine drive box.

As a source of compressed air could be used compressed air generators TA-8 or TA-6B type installed on a plane.

Sequence diagram is defined by start automatic engine start panel, installed on the aircraft.

*Engine electric equipment* provides:

- control of units taking part in engine start-up;
- limiting gas temperature downstream the low-pressure turbine, depending on the engine operating conditions on the ground and in flight;
- limit value restriction of the fan rotor and high pressure compressor rotational speeds;
- issuing signals proportional to the temperature downstream the low-pressure turbine, to the fan, LPC and HPC rotors rotational speeds for the control system.

Engine oil cavities overheating *alarm system*.

The engine provides a place for the sensors, issuing the signal of excess temperature in the interior (oil) engine cavities. When overheating signal appears the engine must be turned off.

*Engine Mount.* The engine is mounted on the aircraft on the pylon by the top, bottom or lateral mount units.

The engine is equipped with the *means of early detection of faults* (vibration control indicators, the fuel and oil filters pressure drop control indicators, thermo-chip-to-indicators, and the minimum oil level control indicator).

The housing of the engine is provided by special holes for inspection the following parts:

- ■ rotor blades of all stages of the low-pressure compressor;
- ■ rotor blades of all stages of the compressor of a high pressure;
- ■ exterior and interior walls of the flame tube; working fuel spray nozzles;
- ■ nozzle unit vanes of high-pressure turbine;
- ■ rotor blades of the high pressure turbine;
- ■ rotor blades of the low pressure turbine;
- ■ rotor blades of all fan turbine stages.

The engine design is made with a view to ensuring the principle of modular assembling. The engine is divided into 12 major modules (Figure 1.3): the fan impeller, straightener fan unit, the fan shaft, low-pressure compressor, a drive box, back support, fan turbine, low pressure turbine rotor, the turbines supports housing, high pressure turbine rotor, combustion chamber, intermediate casing, assembled with HPC. Each module is a complete structural and processing unit and may be (except the main module of the twelfth) removed and replaced without disassembling of adjacent modules. The modular engine design provides the ability to restore its serviceability by replacement parts and units in operation, and high controllability facilitates the transition from preventive maintenance to service as.

On each engine components are mounted, ensuring operation of the engine and the aircraft systems.

Fuel pumps unit (unit 934), a fuel flow adjuster (935MA unit), and the pilot fuel solenoid valve provide operation of supply systems and fuel flow control.

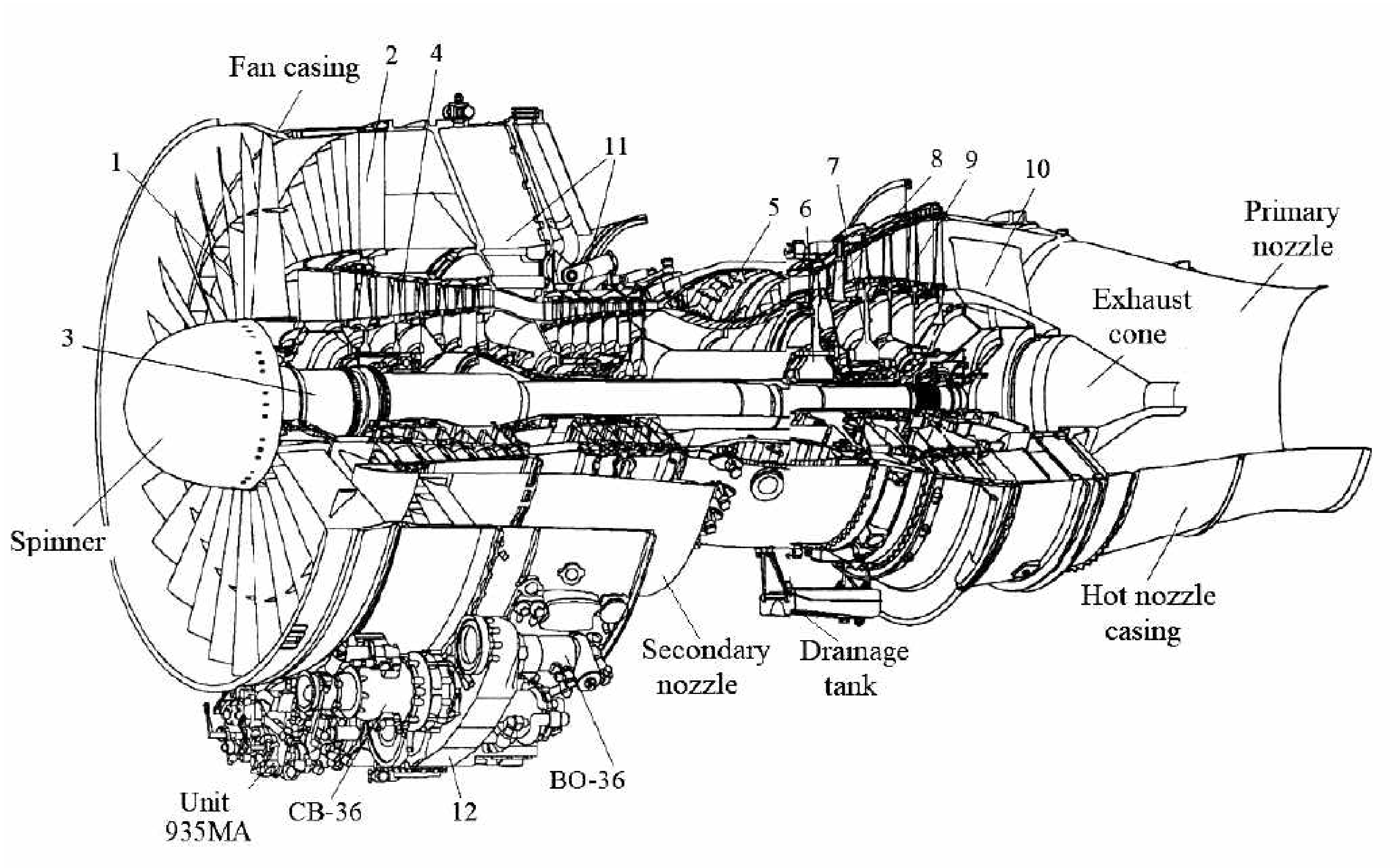


Figure 1.3 – Main engine modules:
1 – the fan impeller; 2 – the fan straightener; 3 – the fan shaft; 4 – the low pressure compressor; 5 – the combustion chamber; 6 – the high-pressure turbine rotor; 7 – the low-pressure turbine rotor; 8 – the housing of turbine supports; 9 – the fan turbine; 10 – the rear engine support; 11 – the intermediate casing and the high pressure compressor; 12 – drive box

Oil assembly МА-36 with the control indicator of maximal pressure drop across the oil filter, air separator ВО-36 with oil filter, centrifugal breather ЦС-36, fuel-oil unit 5660Т with the control indicator of maximal pressure drop across the fuel filter, oil tank МБ-36 with oil level sensor service operation of oil system and engine venting system.

Air starter СВ-36, ignition components СКН-11-1 (2 pcs.), sparking-plugs СП-43 (2 pcs.) provide the work of the engine start system.

The operation of engine control and engine monitoring systems is provided by: electronic control system ЭСУ-2, thermocouples assemblies Т 8ОТ, overall pressure ratio measuring system sensor ДОТ-30, engine rotor rotational speed sensors ДТА-10, vibration transducers МВ-31 (2 pcs.), chip-to-control indicator СС-36, thermo-chip-to-control indicator ТСС-Р6 (3 pcs.), a surge control indicator ПС-2-7, hour run resource meter СНР-1, fuel pressure sensor ИМД- 100, oil pressure sensor ИМД-8, receiver П-77.

The engine basic technical data are presented in the Table 1.1.

Table 1.1 – The engine basic technical data

| Parameter | Value |
|---|---|
| ***Takeoff mode*, H = 0, M = 0, ISA** | |
| Thrust, kN | 63.74 |
| Saved to ambient temperature, °C | +15.0 |
| Specific fuel flow rate, kg / (h N) | 0.0365 |
| Air flow rate, kg / s | 253.0 |
| Bypass ratio | 5.57 |
| The total pressure ratio | 17.35 |
| The gas temperature at the turbine inlet, K | 1450 |
| ***Cruising mode*, H = 11,000 m, M = 0.75, ISA** | |
| Thrust, kN | 11.28 |
| Specific fuel flow rate, kg / (h N) | 0.0678 |
| The total pressure ratio | 19.8 |
| ***Rotor rotational speeds*** | |
| Fan rotor rotational speed, rpm | 5400 |
| LPC rotor rotational speed, rpm | 10500 |
| HPC rotor rotational speed, rpm | 14170 |
| ***Overall dimensions,* mm** | |
| Fan diameter | 1,373 |
| The maximum diameter | 1,711 |
| The maximum length | 3,740 |
| Dry weight, kg | 1124 |
| Date of commencement of production: 1977 | |
| Program status: serial | |
| Application: passenger aircraft Як-42 / 42Д | |

# 2 COMRESSOR

## 2.1 Overview

The engine compressor is three-cascade, consists of a fan, a low-pressure compressor (LPC) and a high-pressure compressor (HPC).

The ***fan*** has one supersonic stage, designed to increase the energy of air passing through the bypass of the engine, and to a preliminary compression of the air entering the gas path of the engine (Figures 2.1, 2.2).

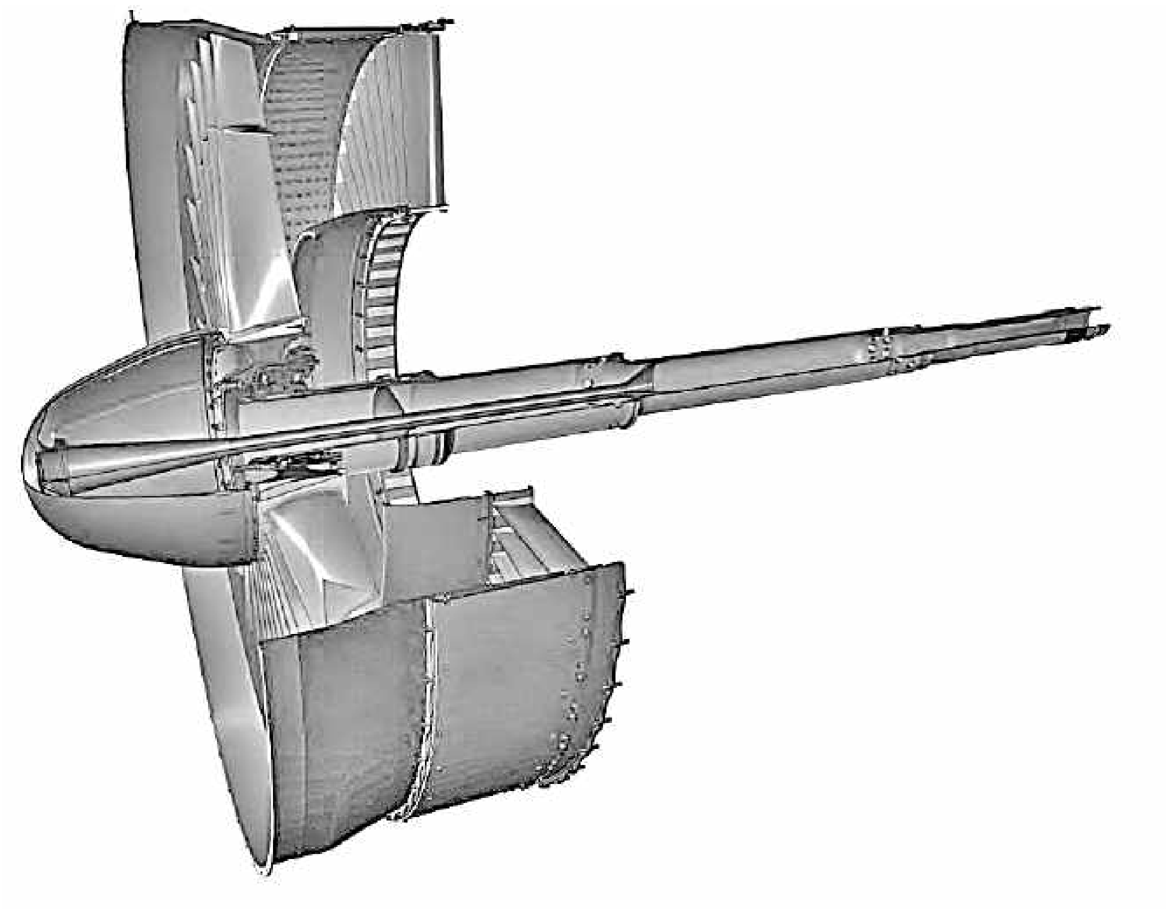

Figure 2.1 – Fan (section of the solid model)

LPC (Figures 2.3, 2.4) and HPC (Figures 2.5, 2.6) are designed to compress air passing through the gas path of an engine and supply this air to the combustion chamber.

The LPC has 6 stages, the first three stages being transonic, and the others - subsonic.

The HPC has 7 subsonic stages.

The main assemblies of each cascade are the rotor and stator. All three rotors are not mechanically interconnected and rotate at different speeds.

The rotor of the fan consists of a disk, working blades and a shaft. Rotors of LPC and HPC are of disco - drum structure. The engine front support assemblies of the rotors with ball bearings are mounted in the fan, LPC and HPC shafts.

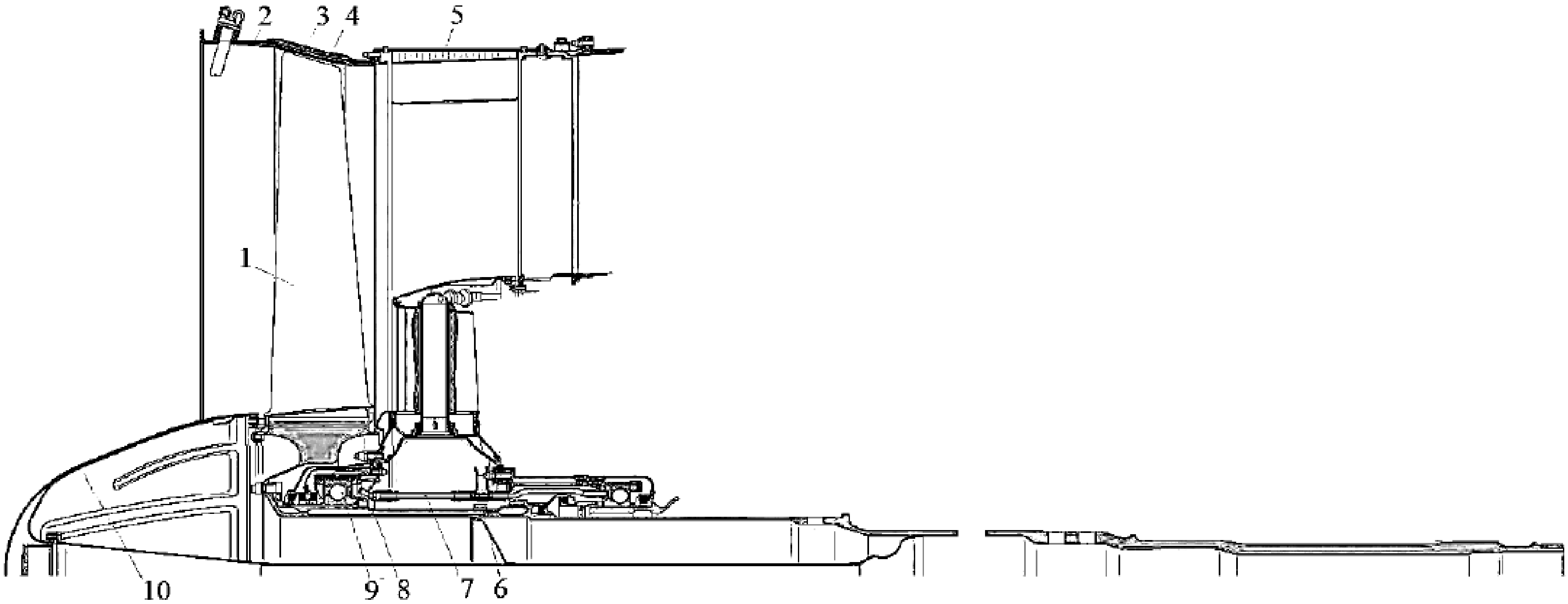


Figure 2.2 – Fan:
1 – the rotor; 2 – housing; 3 – worn-out coating; 4 – carbon fiber reinforced plastic; 5 – straightening vanes; 6 – the filter; 7 – pipeline; 8 – front support; 9 – the ball bearing; 10 – spinner

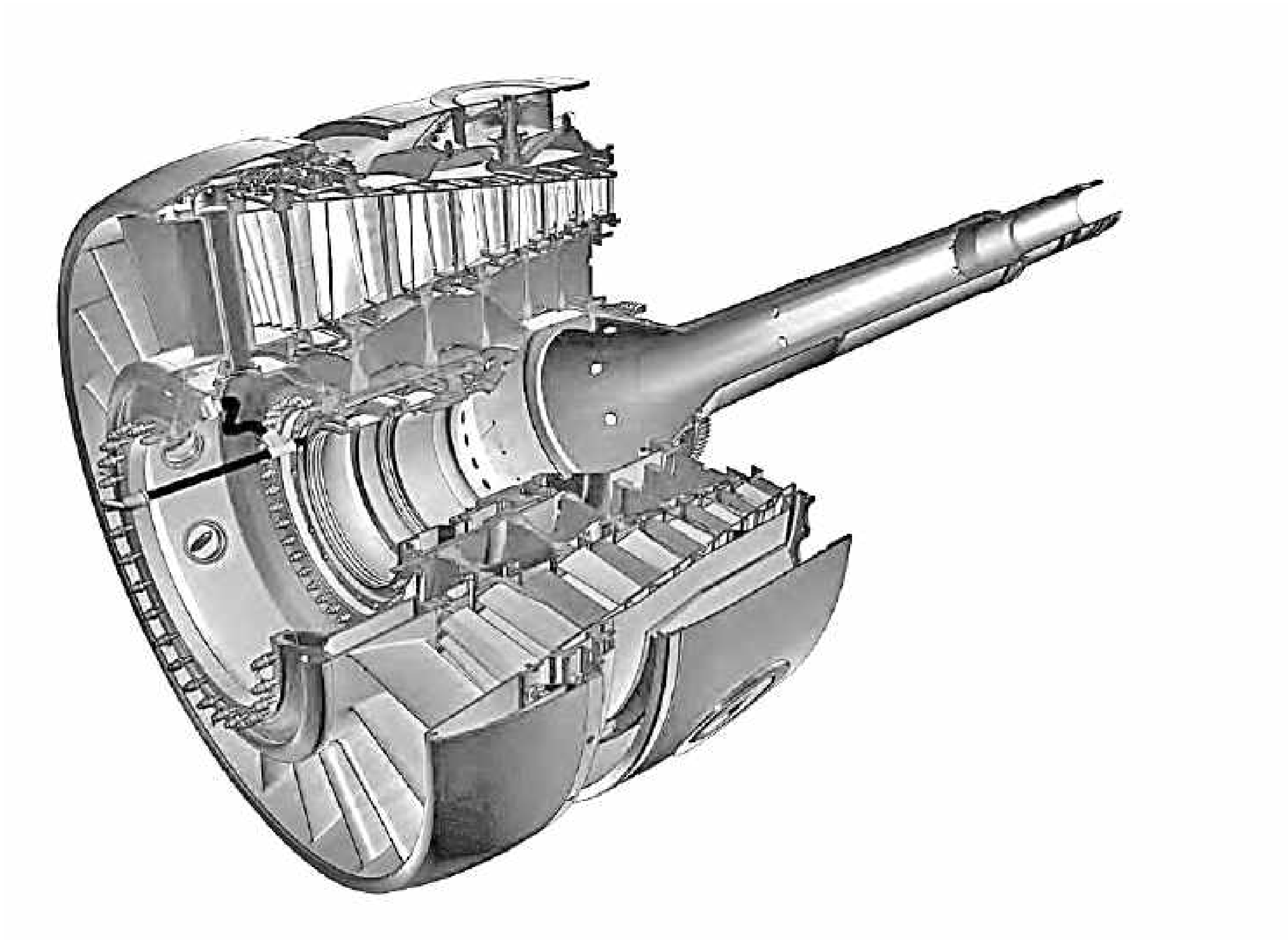

Figure 2.3 – Low pressure compressor (section of the solid model)

A three-stage fan turbine rotates the rotor of the fan; the rotors of the LPC and HPC are rotated by single-stage low-pressure (HPT) and high pressure (HPT) turbines, respectively.

The fan stator consists of a fan casing and straightening vanes located in the secondary flow. LPC and HPC stators are housings in which flow part the straightening vanes are placed.

To adjust the operating mode of the engine low-pressure compressor, there is a LPC IGV with movable vanes.

For the alignment of the operation of the engine cascades, the vanes of the IGV of the high-pressure- compressor are made movable. The angles of installation of LPC and HPC IGV vanes, providing optimal-engine-parameters, are provided during the engine assembling. If necessary, it is possible to adjust the installation angles when testing the engine on the bench.

The flowing part of the fan is made: in the impeller zone - in the form of a tapered annular channel due to a decrease in the outer and an increase in the internal diameters of the path, in the secondary flow and in the transition section to the LPC - in the form of tapering annular channels of a certain shape. The flowing part of the LPC is made in the form of a tapering annular channel due to a decrease in the outer and an increase in the internal diameters of the path.

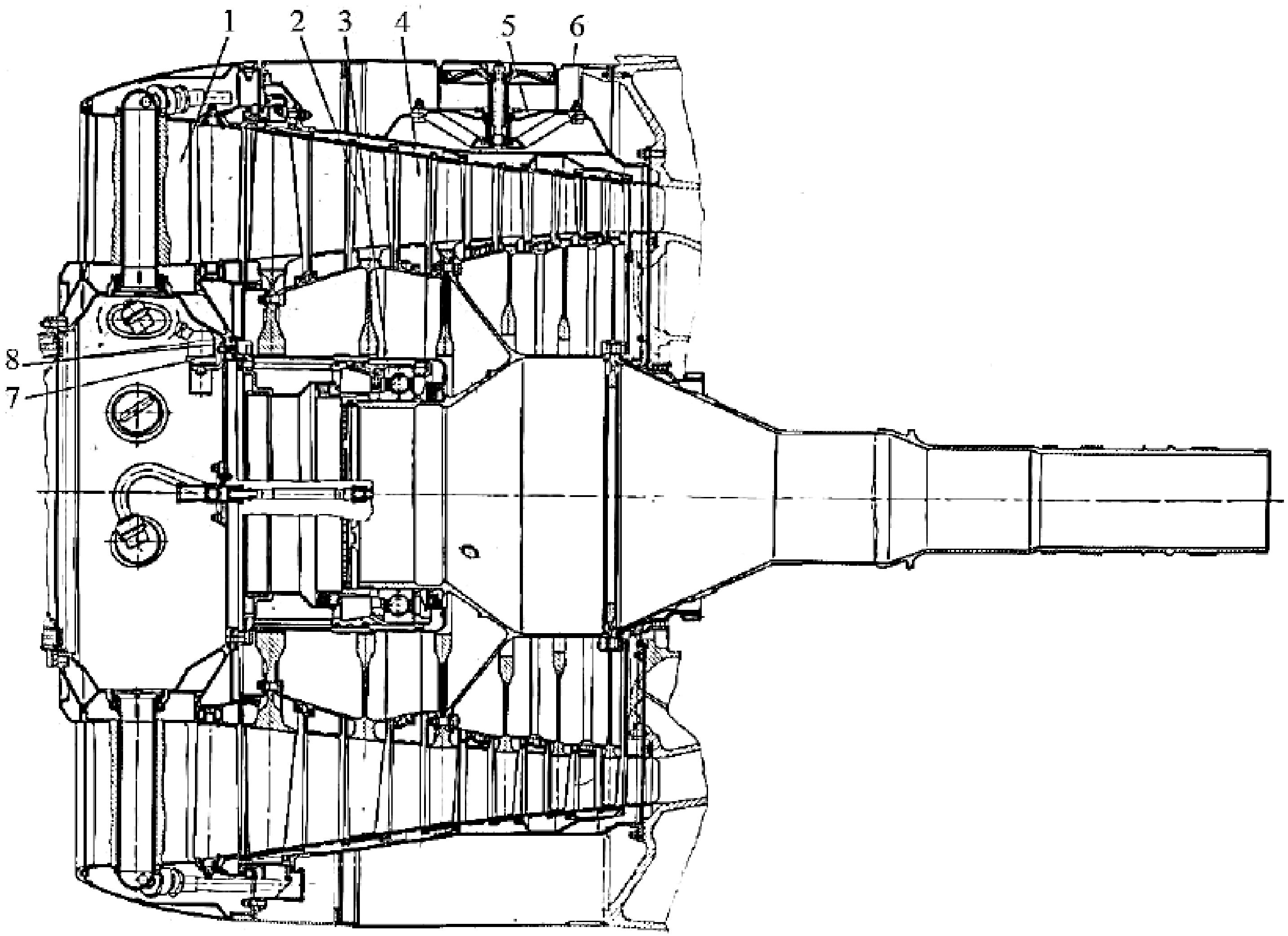


Figure 2.4 – Low pressure compressor:
1 – front housing; 2 – rotor; 3 – front support of the rotor; 4 – stator; 5 – air bleed valve; 6 – a casing;
7 – an adjusting ring; 8 – O-rings

## 2.2 High Pressure Compressor

The high-pressure compressor (see Figures 2.5 and 2.6) consists of the following main units: inlet guide vane 1, rotor 2, stator 3, air bypass valves 10 with casings 12 installed behind the IV stage of HPC, and the front support of the rotor 16.

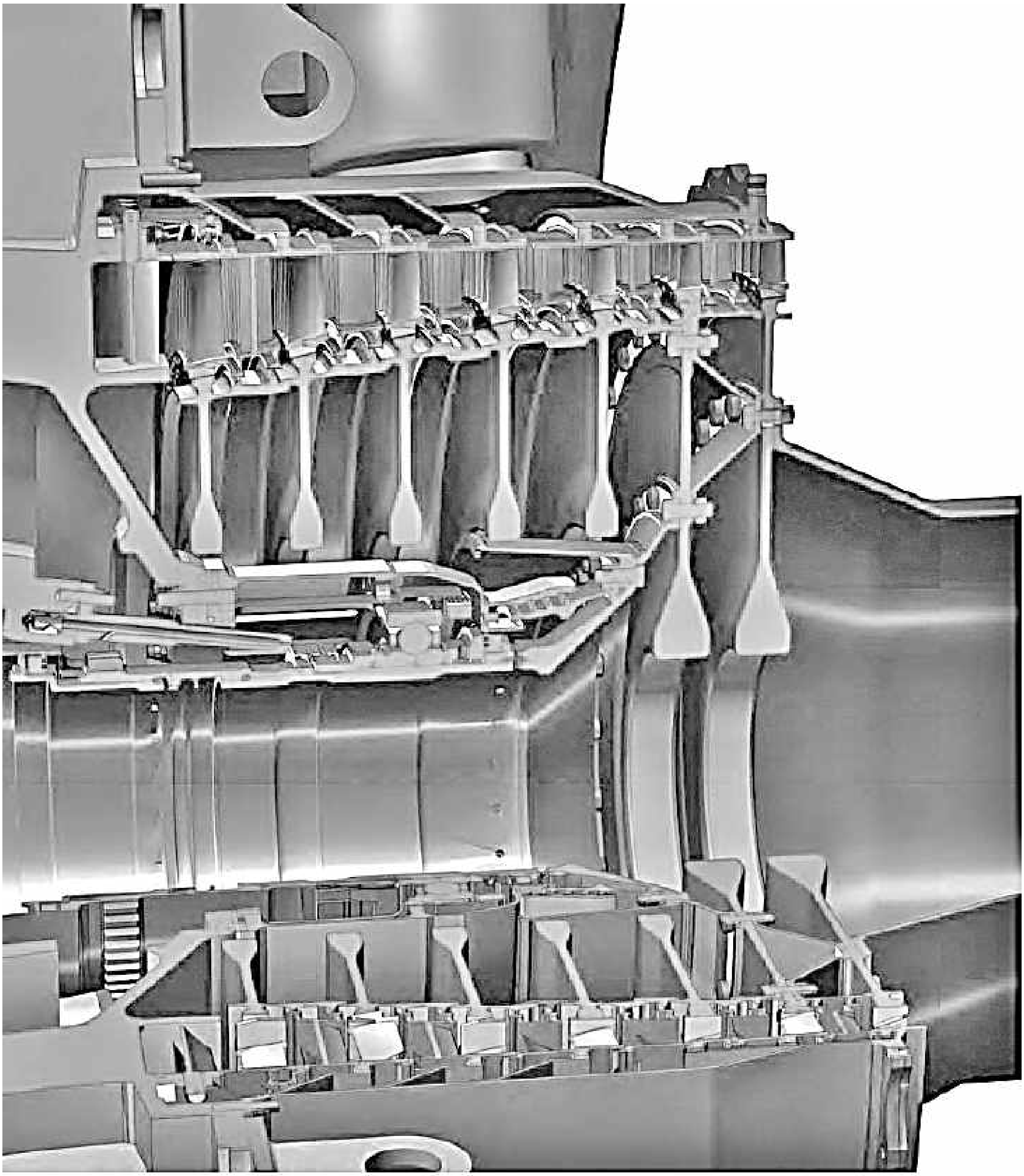

Figure 2.5 – High-pressure compressor (section of the solid model)

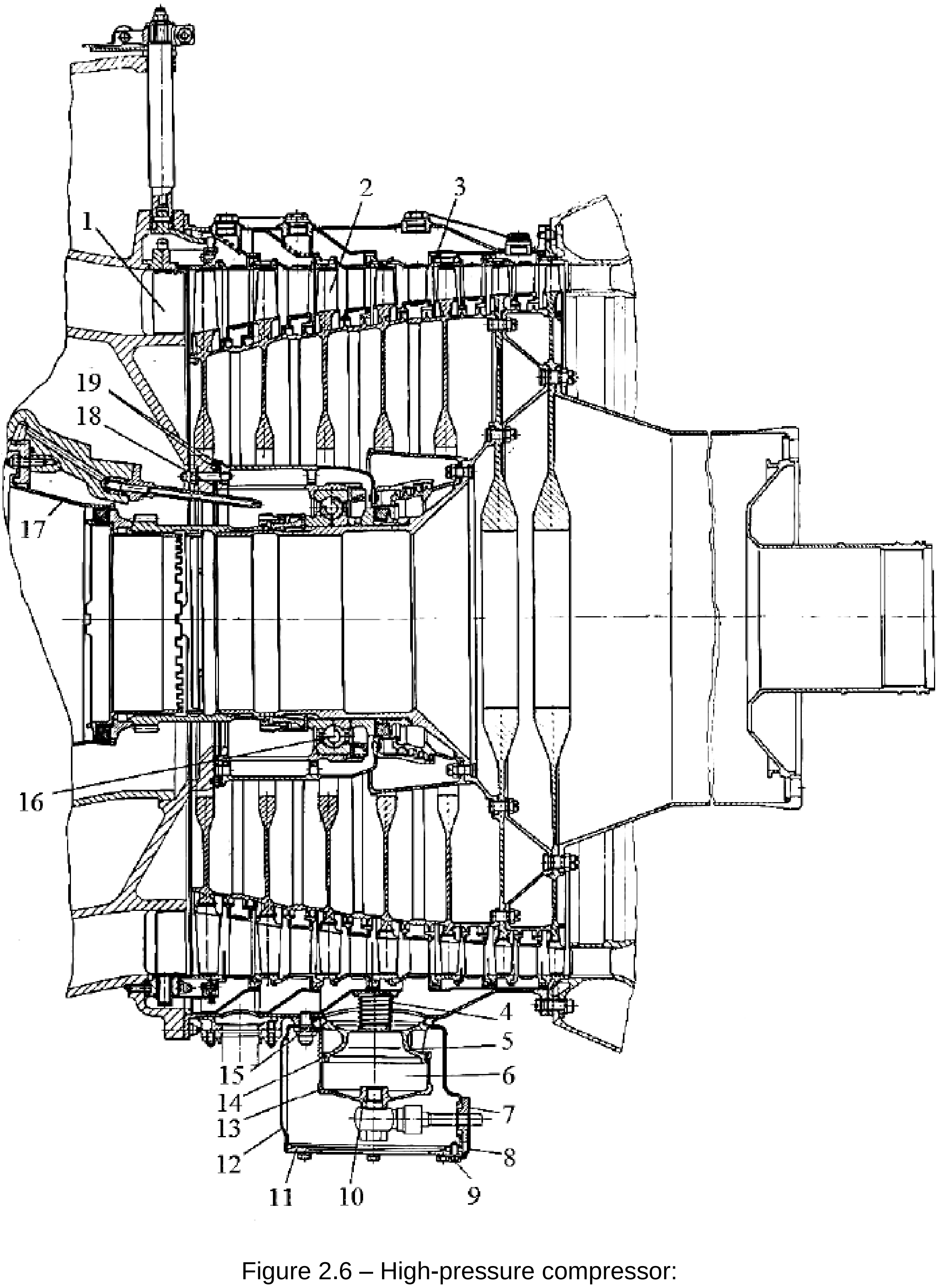


Figure 2.6 – High-pressure compressor:
1 – inlet guide vanes; 2 – rotor; 3 – stator; 4 – a spring; 5 – the valve, 6 – the hermetic cavity of the valve; 7, 14, 19 – sealing rings; 8 – clamp; 9 – screw; 10 – air bleed valve; 11 – ring; 12 – a casing; 13 – housing; 15 – pin; 16 – front support of the HPC rotor; 17 – the bushing; 18 – adjusting ring

### *2.2.1 Inlet Guide Vanes*

The inlet guide vanes (Figures 2.7 and 2.8) are located at the front of the HPC. The IGV design allows you to adjust the angle of installation of the IGV blades on the assembled idle (stopped) engine and fix them in the desired position.

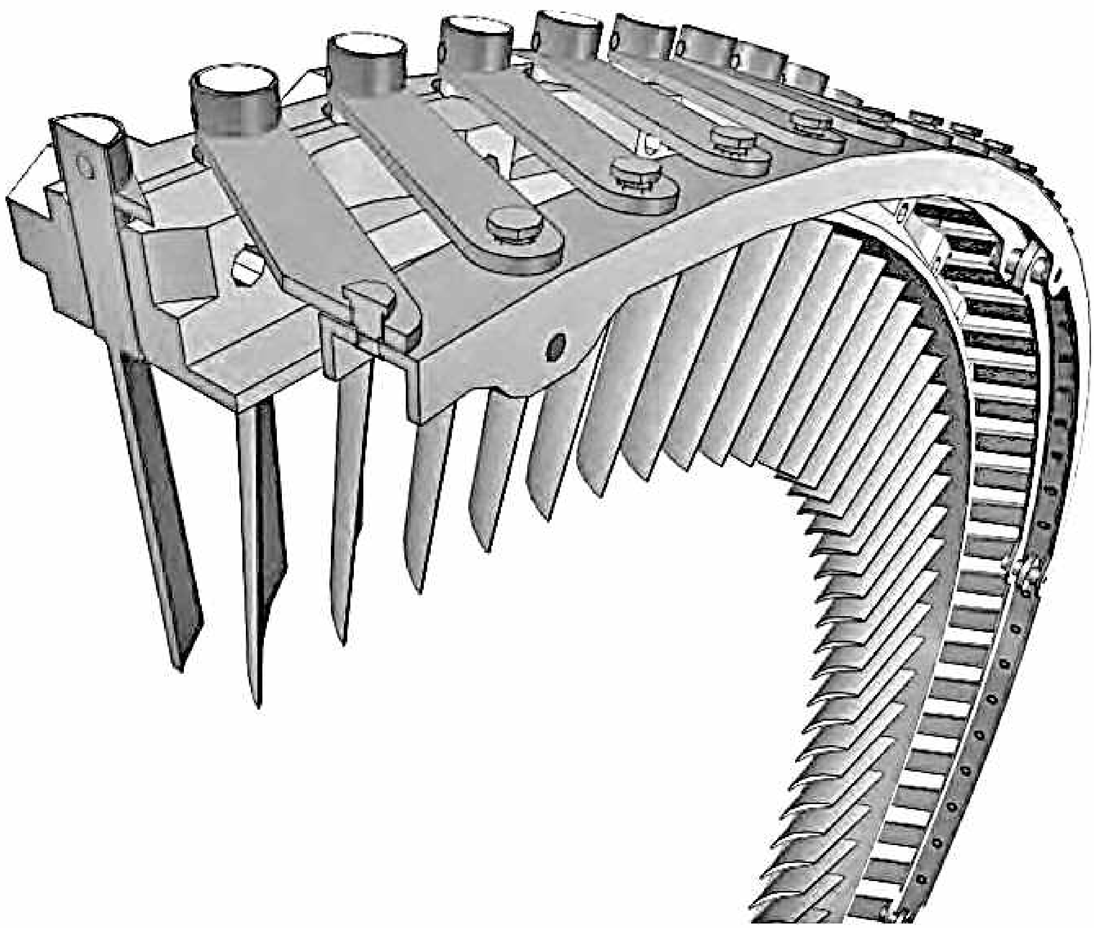

Figure 2.7 – Inlet guide vanes
(section of the solid model)

IGV with the help of ring 2 is installed in the intermediate housing and is attached to it with 48 pins 4 and nuts 5. Ring 2 is split in a plane passing through the axes of the radial holes for the blades. Six axle pins fix the ring halves to each other. In the circumferential direction, the ring is fixed in the intermediate casing by a pin 11.

A bushing 1 is installed on the journal of each IGV blade 23, which serves as a bearing for the blade journals, and a lever 6 fixed by a pin 3. In the radial direction, the blade is fixed with collars of bushings 1 installed in the holes of the ring 2 with an interference fit, and on the blade 23 journals - with a gap.

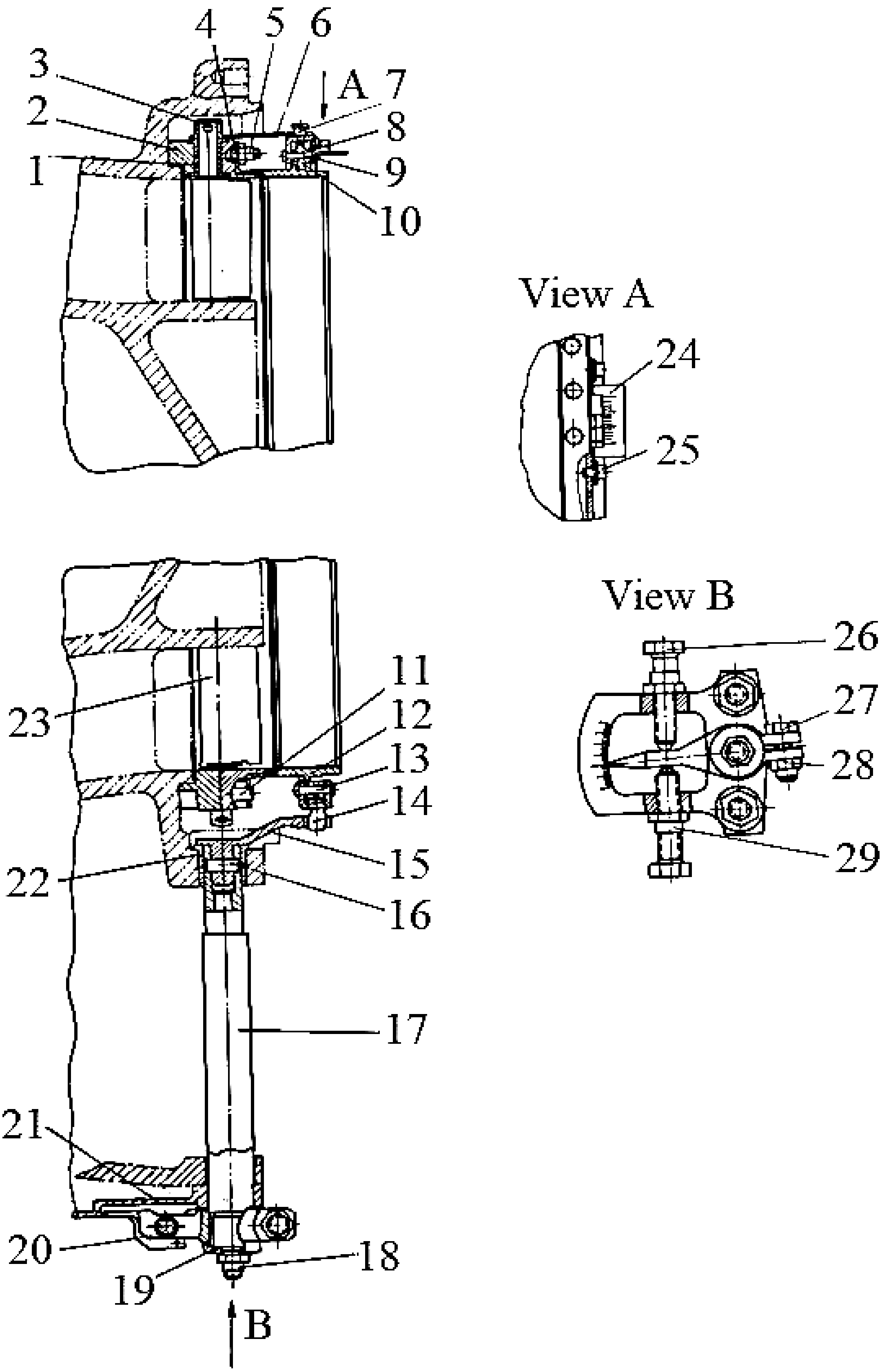


Figure 2.8 – Inlet guide vane:
1, 22 – bushings; 2 – ring; 3, 7, 11, 16 – pins; 4 – pin; 5, 18, 28, 29 – nuts; 6 – lever; 8 – rotation ring; 9 – axle; 10 – roll; 12 – stage I working ring; 13 – rivet; 14 – drive pin; 15 – register lever; 17 – drive roller; 19 – washer; 20 – arrow; 21 – housing-dial; 23 – IGV blade; 24 – limb; 25, 26 – screws; 27 – bolt

The levers 6 of the blades are connected by grooves to the pins 7, radially pressed into the synchronizing ring of rotation 8 of the IGV blades. Twelve rollers 10, mounted on axles 9 in the rotation ring, ensure the concentric position of the latter relative to the engine axis.

The limb 24 is attached to the rotation ring with two screws 25 for additional control of the IGV blades installation angle.

The drive pin 14, the shank of which enters the groove of the drive lever 15 of the IGV rotation and fixation mechanism, is fastened with three rivets 13 in the rotation ring. The pin 16 with the lever is connected to the drive shaft 17, which is centered in the bushing 22 pressed into the hole of the intermediate housing, and in the housing - dial 21, reinforced with two pins and nuts on a specially made platform of the intermediate housing.

Arrow 20 is fastened to the drive shaft shank with splines. The absence of gaps in the spline connection of the arrow and the drive shaft is ensured by tightening the bolt 27 and nut 28 with a certain force. The arrow is fixed along the drive shaft with washer 19 and nut 18.

When assembling IGV, the blades 23 are installed at a certain angle in the channel of the intermediate housing. The limb 24 and the arrow 20 are set in such a way that the marks on the shoulder of the working ring 1 of stage 12 and at the end of the arrow 20 coincide with the mark "0 °" the corresponding scale of divisions, marked on the dial 24 and the housing - dial 21. However, the division on the housing-dial 21 corresponds to one degree of rotation of the IGV blades, and one division on the scale of the dial 24 corresponds to 2 ° of the rotation angle of the IGV blades. The arrow is fixed in the indicated position using adjusting screws 26 and nuts 29.

If it is necessary to change the angle of installation of the IGV blades with the help of adjusting screws, the arrow is set to the required angle on the scale of the housing-dial 21 according to the technology that excludes the influence of the clearances at the joints of the unit on the angle of installation of the blades. In this case, the drive lever 15 rotates in the circumferential direction the synchronizing ring of rotation 8, and the rollers 10 are rolled along the supporting surface of the working ring 1 of stage 12, and by means of the levers 6 they rotate IGV blades 23 to the required angle. After the end of the adjustment, the position of the adjusting screws 26 is fixed by means of nuts 29. The IGV blades, the housing-dial and the rotation ring are made of titanium alloy, the IGV ring is made of aluminum alloy, the rest of the IGV parts are made of steel.

### *2.2.2 HPC Rotor*

The rotor (Figures 2.9 and 2.10) is a seven-stage, disco-drum design, consists of the following main parts: rotor sections of I-V stages 1, impellers of VI stage - 2 and VII stage - 4, spacers 3, front shaft 7 and rear shaft 6.

The rotor section 1 consists of five discs welded into a drum, rotor blades mounted in the rim of each disc using dovetail locks. The drum has a flange with which it joins the impeller 2 of stage VI.

The drum manufacturing technology is similar to the manufacturing technology of the welded section of the LPC rotor. In the shells of the drum, one hole is made between the discs for ejection into the compressor path of condensate or a small amount of oil that accidentally got into the inner cavity of the rotor.

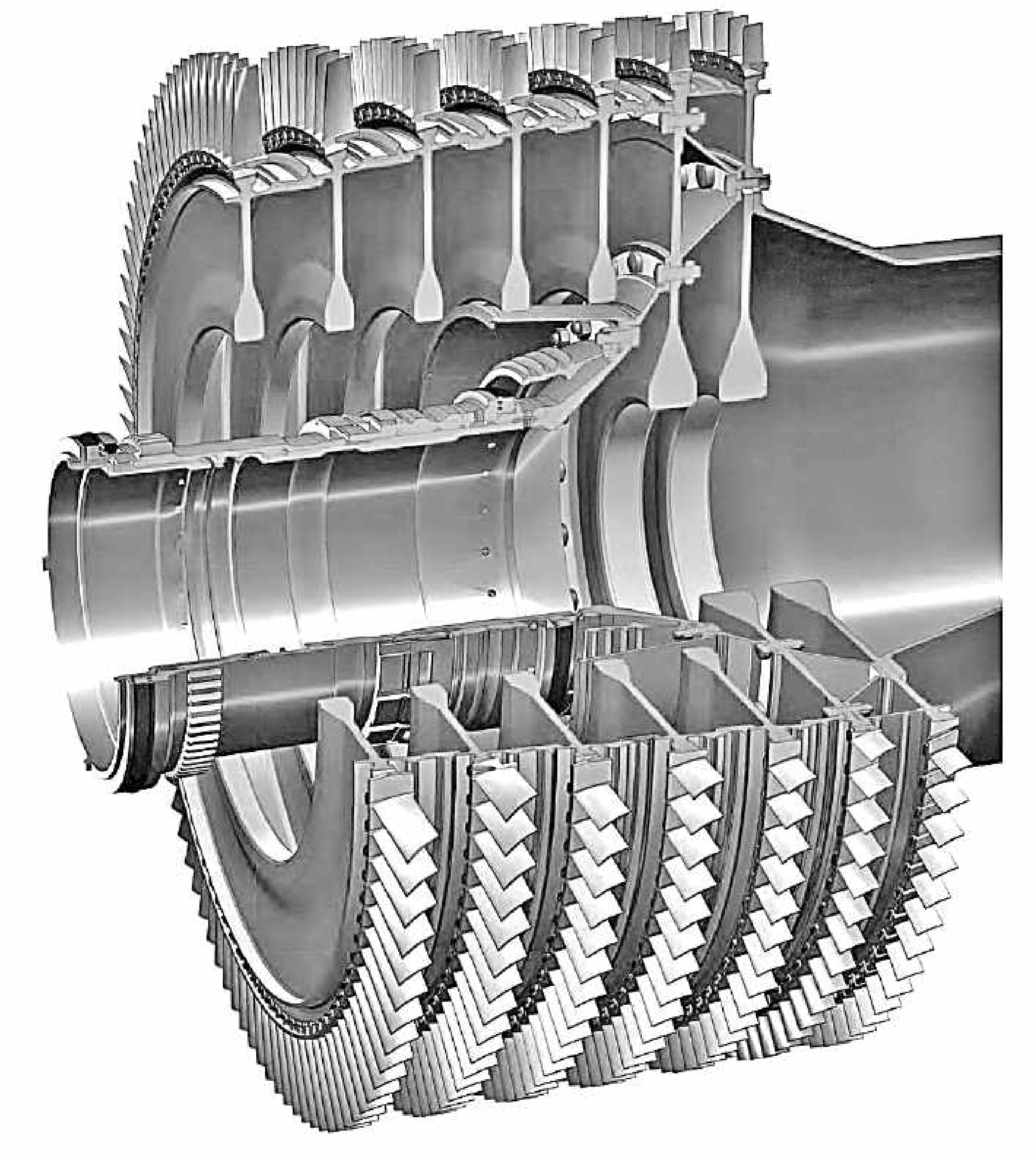

Figure 2.9 – High pressure compressor rotor
(section of the solid model)

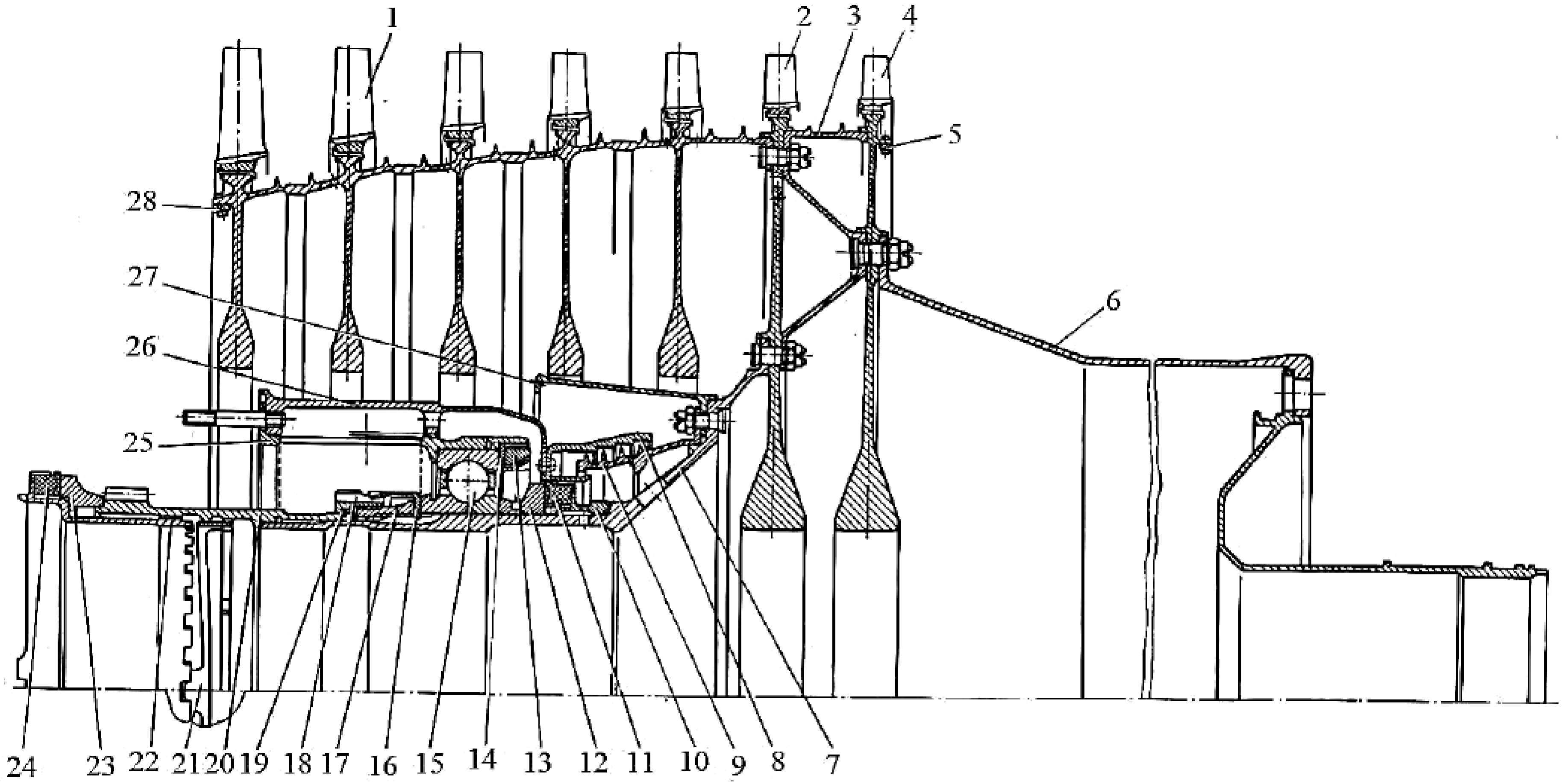


Figure 2.10 – High pressure compressor rotor:
1 – section of rotor stages; 2 – impeller of the VI stage; 3 – spacer; 4 – stage VII impeller; 5, 28 – balancing weights; 6 – rear shaft of HPC; 7 – front shaft of the HPC; 8 – bushing; 9 – labyrinth; 10 – ring; 11, 24 – sealing rings; 12, 23 – thrust rings; 14 – locking sleeve; 13, 17, 18, 22 – nuts; 15 – ball bearing; 16 – locking sleeve; 19 – retaining ring; 20 – drive gear; 21 – lock; 25 – resilient rotor support; 26 – support housing; 27 – screen

One hole in the labyrinth 9 and a hole in the front shaft 7 serve the same purpose. The spacer 3 has two holes in the cylindrical shell for venting the cavity between the VII stage disc and the spacer. On the shells of the drum between the discs and on the cylindrical shell of the spacers, there are two combs of interstage labyrinth seals.

The impellers of the VI and VII stages consist of a disk and rotor blades mounted in the rim using dovetail locks. From axial movement, the blades are fixed in the section and impellers with plate locks and thrust collars on the blade locks.

The impeller of the VI stage 2 is pulled together with the upper flange of the spacer 3 and rotor sections 1 by thirty-two close-fitting bolts, and with the front shaft 6 and the lower flange of the spacer - by twenty-four close-fitting bolts.

There are 16 holes in the VI stage disc; in the spacer - 8 holes for air passage for heating the wheel hubs of the VI and VII stages. The spacer, the impeller's 7th stage 4 and the high-pressure turbine shaft are tightened with 24 tight-fitting bolts. To hold the bolts in the axial direction when assembling the rotor at the junction of the spacer with the VII stage disc, retaining rings are installed on the bolts. The nuts of all joints of the rotor are counter-tightened by crimping into the grooves made on bolts.

Before assembling the HPC rotor, the rotor section of the I-V stages and the impellers of the VI and VII stages are balanced by rearranging the rotor blades and setting balancing weights, the front shaft by removing metal in two correction planes. The assembled HPC rotor is balanced by placing balancing weights 28 and 5 on the disks of stages I and VII.

Discs and rotor blades of rotor section I are made of titanium alloy, front shaft 7, rear shaft 6, disks and rotor blades of VI and VII stages 2 and 4, spacer 3, bolts and nuts are made of nickel-based alloy.

### *2.2.3 HPC Stator*

The stator (Figures 2.11 and 2.12) consists of a housing 5, working rings 13 and guide vanes 21.

The compressor housing is one-piece, welded. Front 2 and rear 14 flanges are butt welded to the casing.

On the front flange, by which the housing is attached to the intermediate housing, there are 48 holes for the fastening pins and one hole 3 for the fixing pin. On the rear flange there are 60 holes for the screws fastening to the combustion chamber housing and one hole into which the pin 15 is pressed, fixing the circumferential position of a set of working rings of V, VI, and VII stages and guide vanes of IV, V and VI stages. Bosses 4, 6 and 11 with holes are welded into the holes of the casing. The boss 4 is used to control the readings of the dial 24 IGV (see Figure 2.8), and the bosses 6 (see Figure 2.12) and 11 are used to monitor the state of the rotor blades using an optical device. When the engine is running, the holes in the bosses are closed with screw plugs.

On the outer surface of the housing, flanges are welded in three rows around the circumference.

In the first row (counting from the front flange 2) there are two air bleed flanges downstream the II stage of the HPC for aircraft needs.

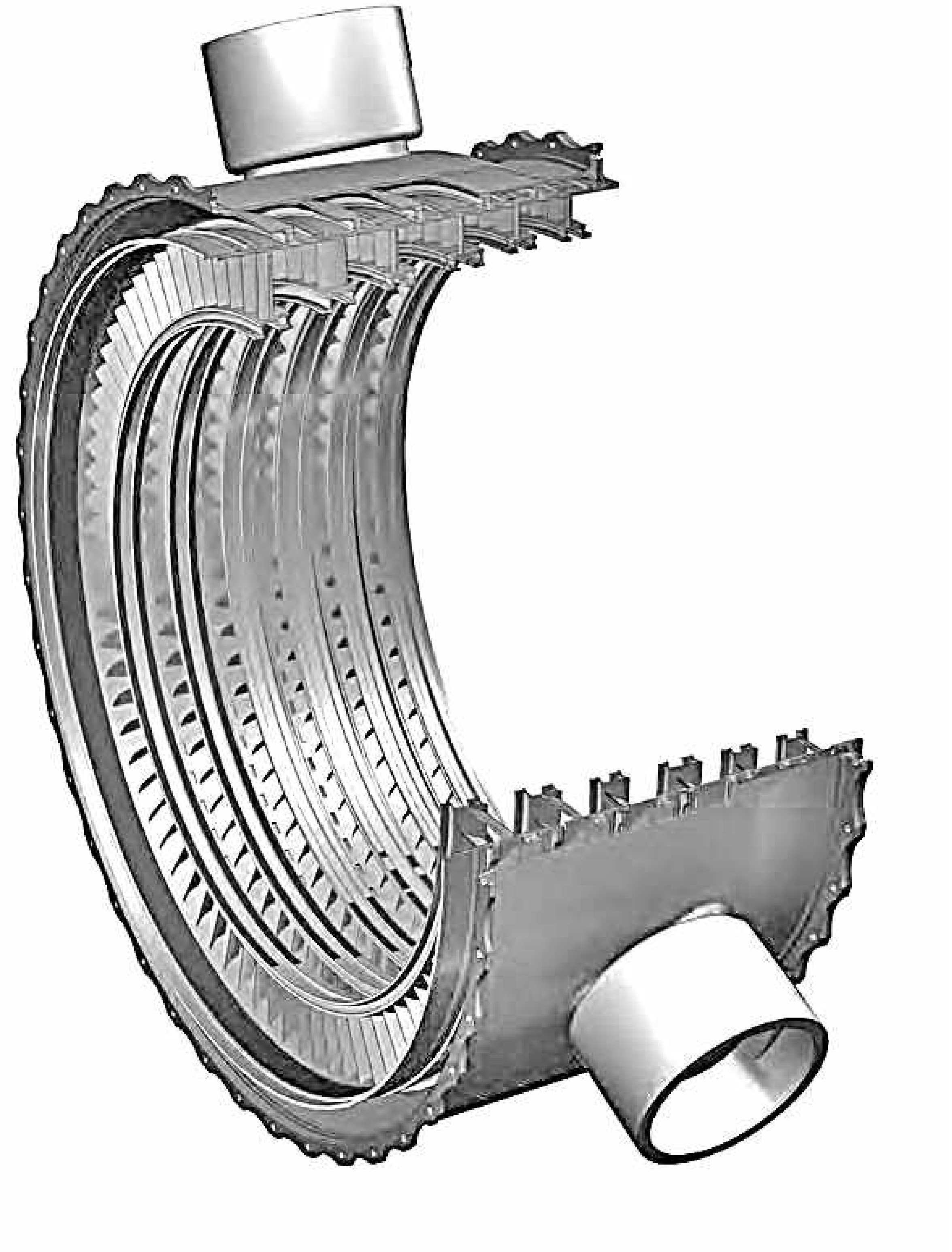

Figure 2.11 – High pressure compressor stator
(section of the solid model)

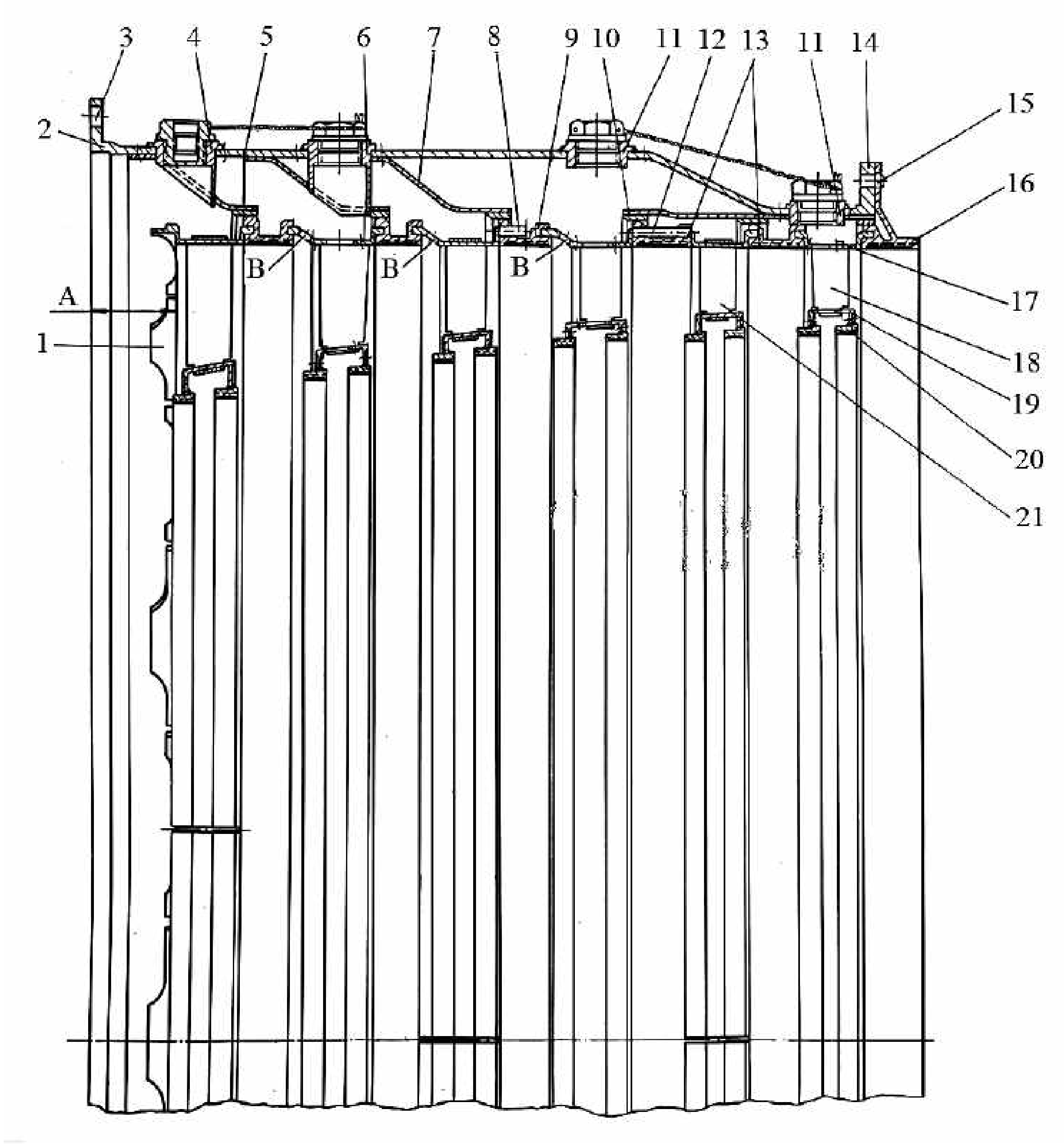


Figure 2.12 – High pressure compressor stator:
1 – protrusions of GV I stage; 2 – front flange; 3 – hole for the fixing pin; 4 – boss for monitoring the readings of the IGV limb; 5 – housing; 6 – boss for inspection of the rotor blades; 7 – centering shell; 8 – fixing pin; 9 – an adjusting ring; 10 – centering shell; 11 – bosses for inspection of the rotor blades; 12 – pin; 13 – working rings; 14 – rear flange; 15 – fixing pin; 16 – stage VII working ring; 17 – outer ring; 18 – vane; 19 – inner ring; 20 – labyrinth ring; 21 – guide vane

In the second row, there are five air bleed flanges downstream the III stage of the HPC, of which three bleed flanges are used for turbine cooling and one air bleed flange for the engine anti-icing system and air intake heating.

In the third row, there are four flanges, of which - one air bleed flange downstream to stage IV for controlling the LPC air bypass valves and three flanges for installing air bypass valves from the IV stage of the HPC.

On each of the last three flanges, a conical surface is made - a saddle, along which sealing occurs during the closing of the air bypass valve. Three pins 15 are pressed into the flanges (see Figure 2.6), which serve to center the valve relative to the flange saddle.

In addition, six threaded bosses are welded on the HPC casing at the top near the vertical plane and on both sides near the horizontal, which serve to fasten the lugs for the engine suspension rods.

Three shells 7 (see Figure 2.12) and shell 10 are welded to the inner surface of the casing by resistance welding, which serve to center the set of working rings and guide vanes in the casing and form receivers for air intake and bleeding.

Working rings of all stages are one-piece; guide vanes (GV) of all stages have connectors in diametrical planes. When installed in the housing, the GV II stage connector relative to the GV I stage connector and the connector of each subsequent GV relative to the previous one are shifted by 90 °.

The outer 17 and inner 19 rings of all GV are turned and connected to the blades 18 by electric riveting followed by soldering. Two labyrinth rings of 20 interstage air seals are welded to the inner rings.

Protrusions I on the outer ring of the 1st stage serve for axial fixation of the rotation ring HPC IGV 8 (see Figure 2.8).

On the tapered sections of the outer rings of the II, III and IV stages, holes B are made (see Figure 2.12) for air intake and bleeding.

With the help of end collars on the outer rings, the guide vanes are centered in the corresponding end grooves of the working rings 13. The transmission of torque from the gas-dynamic forces acting on the crown of the blades of the GV is carried out using axial pins 12 pressed into the body of the working rings and inserted in the counter grooves of the centering collars GV outer rings. Torque from GV of I - III stages is transmitted through the working ring of stage I 12 (see Figure 2.8) to ring 2 of the HPC IGV and then to the intermediate casing.

The torque from the GV IV - VI stages is transmitted through the working ring of the VII stage 16 (see Figure 2.12) to the HPC housing. Since the torque from stage to stage is summed up, the number of pins 12 transmitting it increases from eight on the working rings of stages III and V to twenty-four on the working rings of stages I and VII. For fixing in the circumferential direction, the working ring of the IV stage has a pin 8, which fits into the groove of the centering shoulder of the GV III stage. The adjusting ring 9 serves to ensure the specified axial dimension GV during assembling of the HPC stator.

The working rings and labyrinth rings of the GV of all stages have soft, easy-to-wear coatings.

The HPC body is made of titanium alloy, the working rings and guide vanes are made of steel.

### *2.2.4 Air Bleed Valves*

To ensure stable operation of the high-pressure compressor, three air bleed valves are mounted behind the IV stage of the HPC. The air bleed valve (see Figure 2.6) consists of a housing 13, a valve 5 with two O-rings 14 and a spring 4.

The valve housing 13 is centered relative to the conical surface of the flange of the HPC housing by three pins 15 pressed into the flange and mounted on three pins.

With the help of O-rings 14, a sealed cavity 6 is formed between the housing 13 and the valve 5.

The air bleed valves are open when the engine is not running and during low speed operation. The valve 5 is pressed from the housing flange by the spring 4 to the extreme position - the cavity of the receiver of the housing communicates with the air path of the secondary flow.

When a certain value of the total compression ratio is reached, the bleed valve control automat opens access to air behind HPC into cavity 6, under the action of which the valve moves to the housing flange, overcoming the spring force. Having reached the flange, the conical belt of the valve fits snugly against the conical surface of the housing flange and blocks the path of air from the receiver cavity of the body to the secondary flow.

When the engine switches to idle, the air from the cavity 6 is vented into the atmosphere and the valve 5 is pressed by the spring 4 from the housing flange to the extreme position.

Valve 5 is made of titanium alloy; other parts are made of steel.

With the help of casings 12 and branch pipes, air from the HPC bleed valve is diverted to the secondary flow of the engine. The pipeline for supplying air to the cavity 6 of the bleed valve is sealed in the hole of the casing 12 with a ring 7 and a clamp 8. To seal the air outlet on the casing 12, ring 11 is fastened with seven screws 9.

### *2.2.5 Front Support of HPC*

The front support (see Figure 2.10) is an angular contact ball bearing 15 with a split inner race. The outer bearing cage is installed in an resilient element 25 of the "squirrel wheel" type and, together with a locking sleeve 14, is clamped by a nut 13. A support housing 26 is put on top of the resilient element.

A radial gap A is provided between the support housing and the resilient element, within which the bearing can move, and with them the HPC rotor during engine operation.

The flange of the resilient sleeve is centered on the intermediate casing flange and is pressed against it together with the adjusting ring 18 (see Figure 2.6) by the support housing flange 26 (see Figure 2.10) using eighteen studs.

The joint of the adjusting ring with the flanges of the support body and the intermediate casing is sealed with rubber rings 19 (see Figure 2.6).

A bushing 8 (see Figure 2.10) of a non-leakage seal is riveted to the shell of the support housing, into which a sealed split graphite ring 11 is inserted, placed between the thrust ring 12 and the collar of the ring 10. Under the action of the differential pressure in the air cavity of the rotor and in the oil cavity of the bearing, the graphite ring 11 is pressed against the end face of the ring 12, while simultaneously pressing with its outer diameter against the inner surface of the sleeve 8. Thus, oil cannot penetrate into the rotor cavity.

On top of the support housing, a screen 27 is mounted, which, together with the labyrinth 9, is attached to the front shaft 7 with twelve bolts.

Parts installed on the front shaft 7 of the HPC rotor: rings 10 and 12, the inner cage of the ball bearing and the lock sleeve 16 are tightened with a nut 17. On the front shaft 7, a drive gear 20 is also installed to drive the engine units: torque is transmitted using splines, in the axial direction; the gear is pressed against the shaft end by the nut 18 through the retaining ring 19. The nuts 17 and 18 are locked by the sleeve 16.

A thrust ring 23 is installed on the gear 20 and tightened with a nut 22, locked with a lock 21 relative to the gear 20. Between the ring 23 and the collar of the nut 22, a graphite sealing ring 24 is placed. Under the action of a pressure difference, the ring 24 is pressed against the end of the ring 23, while being centered on the sleeve 17 (see Figure 2.6) installed in the central drive housing. Therefore, oil cannot enter the rotor cavity.

Three nozzles mounted on the central drive housing lubricate the ball bearing.

Shield 27 and ring 10 are made of titanium alloy. The remaining parts of the HPC rotor front support are made of steel and nickel-based alloys.

## 3 INTERMEDIATE HOUSING ASSEMBLY

The intermediate housing assembly (Figures 3.1, 3.2) located between the low-pressure compressor and the fan straightening vanes on the one hand and the high-pressure compressor on the other is designed for:

the formation of primary and secondary gas-air paths on its site;

the arrangement of units and drives to them;

the arrangement devices that serve and control the operation of the engine and aircraft;

the arrangement engine mounts.

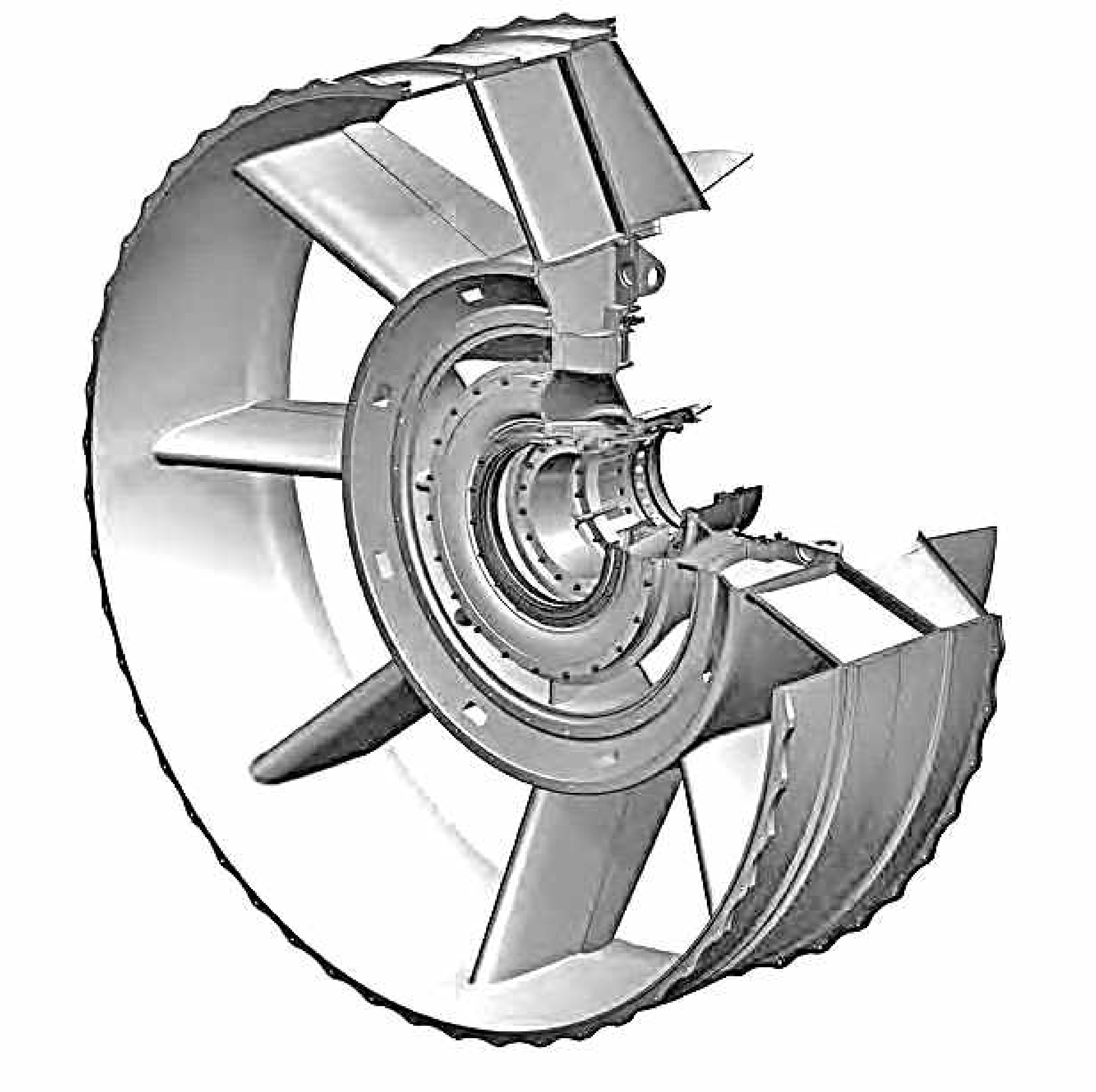

Figure 3.1 – Intermediate housing (front view)

And it is also one of the main parts of the power circuit of the engine.

The intermediate housing assembly includes: an intermediate housing, a central drive, a drive column and a drive box.

On the drive box and intermediate housing the following units and devices serving the engine and aircraft are installed:

– a hydraulic pump;
– a fuel flow governor;
– a fuel pumps unit;
– a hydraulic drive with an alternator;
– an oil assembly;
– a centrifugal breather;

– an air-oil separator;
– an air starter;
– a chip detector;
– overheating sensors;
– non-contact sensors for measuring the LPC and HPC rotor speeds;
– two ignition coils;
– solenoid valve for starting fuel;
– oil tank; fuel-oil unit.

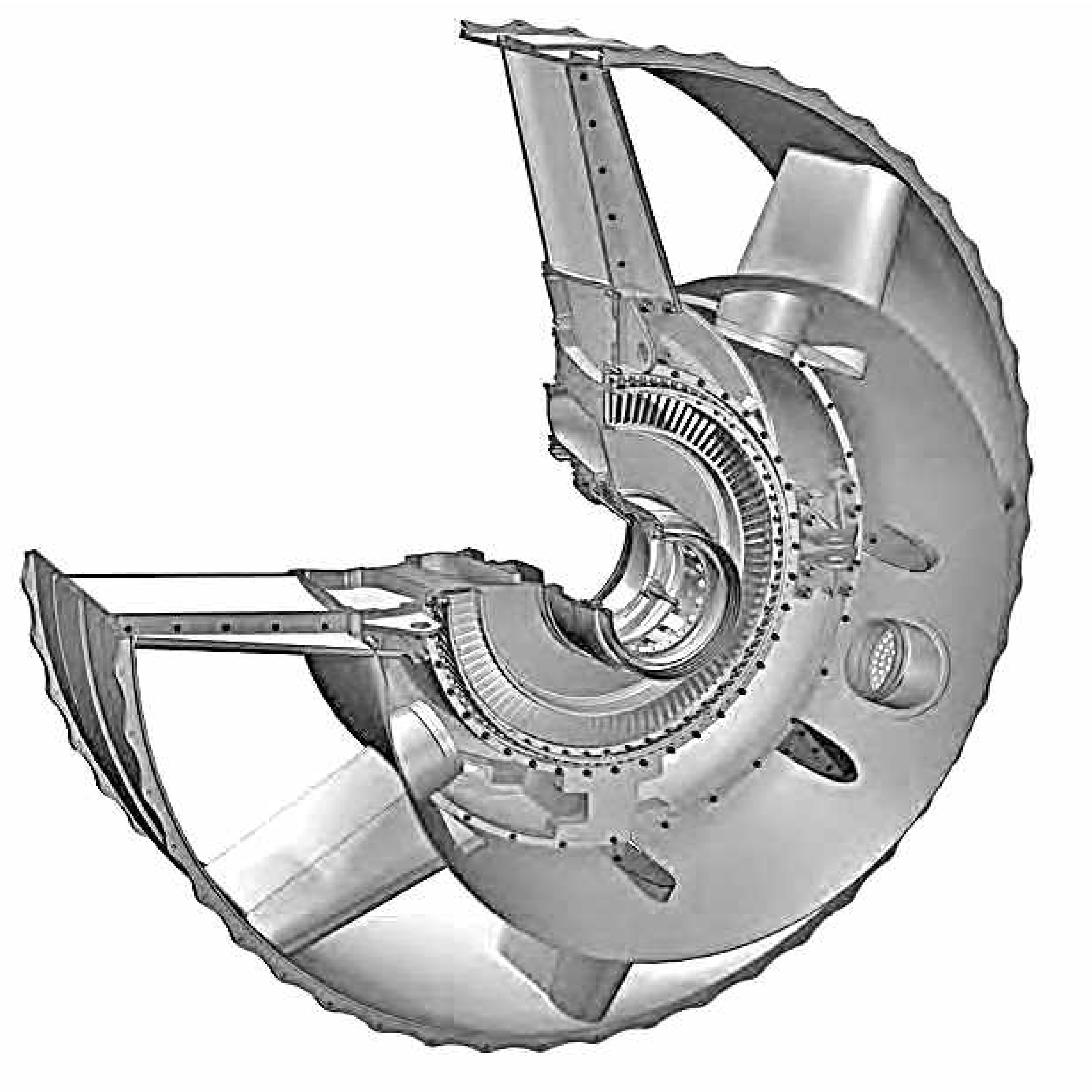

Figure 3.2 – Intermediate housing (rear view)

### 3.1 Central Drive

The central drive (Figures 3.3, 3.4) consists of a cast magnesium housing 1, a labyrinth sleeve 16 with a heat-resistant sealing coating applied to it, fixed to housing 1 by eighteen pins 15 and nuts 14, three nozzles 3 with filters for supplying oil to the HPC rotor bearing, a central drive bevel gear unit, consisting of two bevel gears 7 and 10, a spur gear 5 and a sleeve 4 of an air-tight seal of the HPC support cavity.

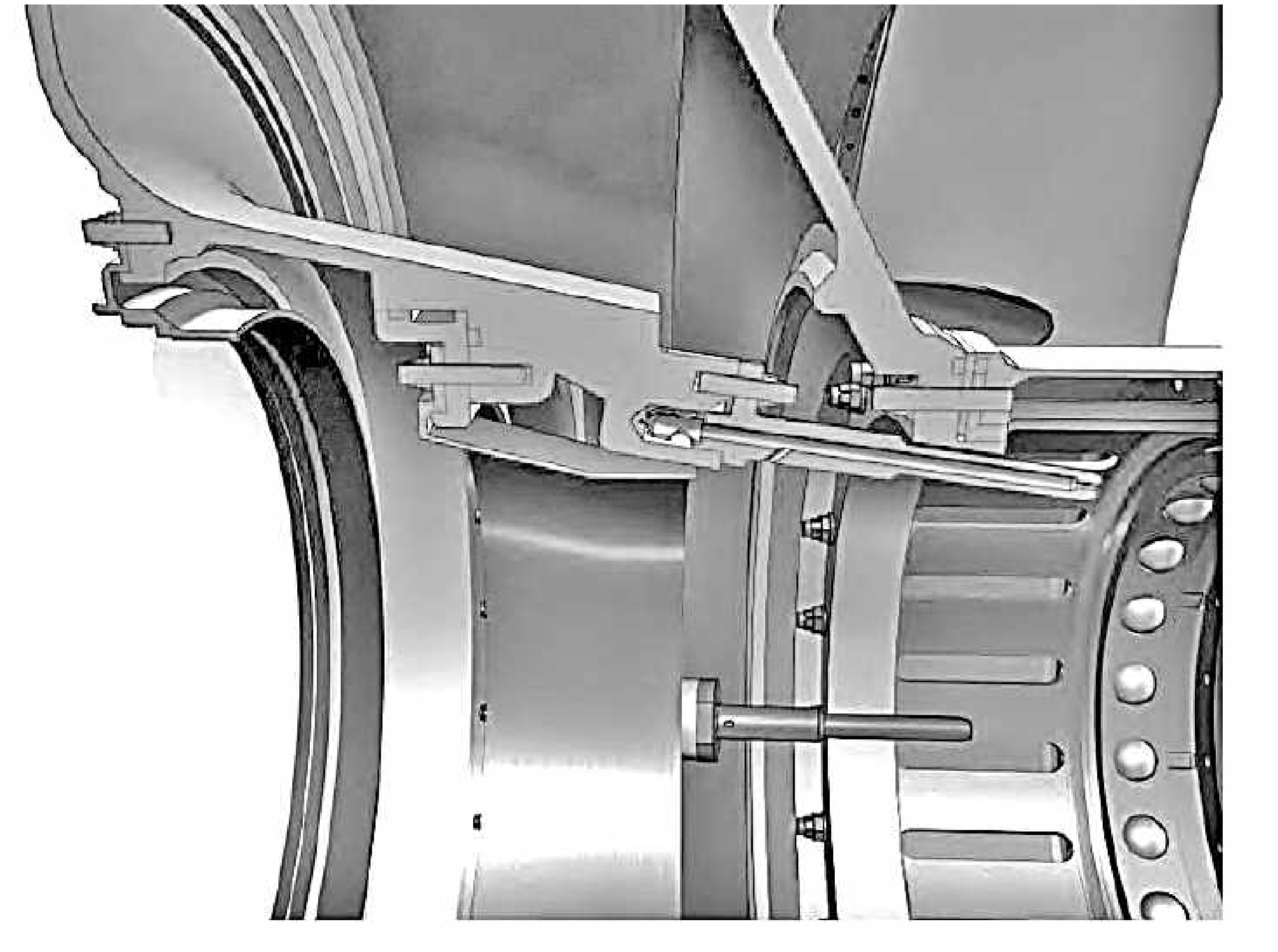

Figure 3.3 – Central drive (solid model section)

The gears are supported by rolling bearings 6, 8, 9, 11, located on both sides of the gear rims. Lubrication of these bearings is carried out through a hole in the housing of the central drive 1, communicated by channels with channel 2, which supplies oil to nozzles 3.

The bevel gear unit is located in special tides, made in one piece with the central drive housing 1.

The housing 1 is attached to the intermediate housing with a flange 13 and is centered by a precisely machined cylindrical collar 12 on the bore of the intermediate housing.

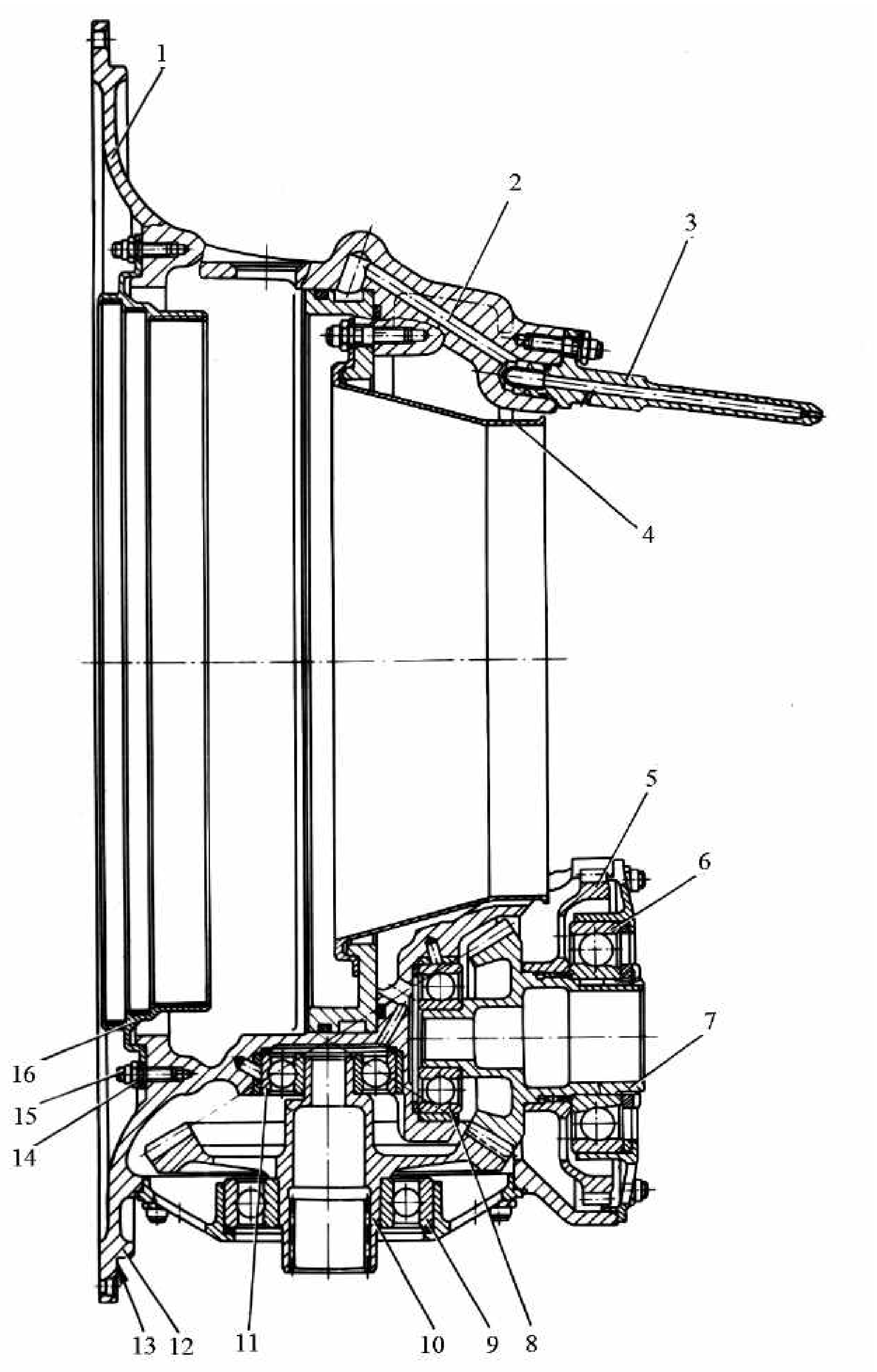


Figure 3.4 – Central drive:
1 – housing; 2 – oil supply channel; 3 – oil nozzle; 4 – bushing of an air-tight seal; 5,7,10 – gears; mountings to the intermediate casing; 6,8,9,11 – ball bearings; 12 – centering belt; 13 – flange; 14 – nut; 15 – stud; 16 – labyrinth bushing

## 4 COMBUSTION CHAMBER

The combustion chamber is designed to organize the combustion of fuel and the supply of gases to the vanes of the high-pressure turbine nozzle.

The combustion chamber (Figures 4.1, 4.2) is of the annular type, consists of a housing 9, a flame tube 8, a diffuser 1 with straightening vanes of a high-pressure compressor VII stage, a fuel manifold 3, fuel spray nozzles 6, fuel supply pipelines 5 and two pilot igniters 7.

The air path of the combustion chamber is an annular channel formed by the shells of the diffuser 1, of the housing 9 and of the inner casing 10 of the nozzle vanes. In the air path of the chamber, there is a flame tube 8.

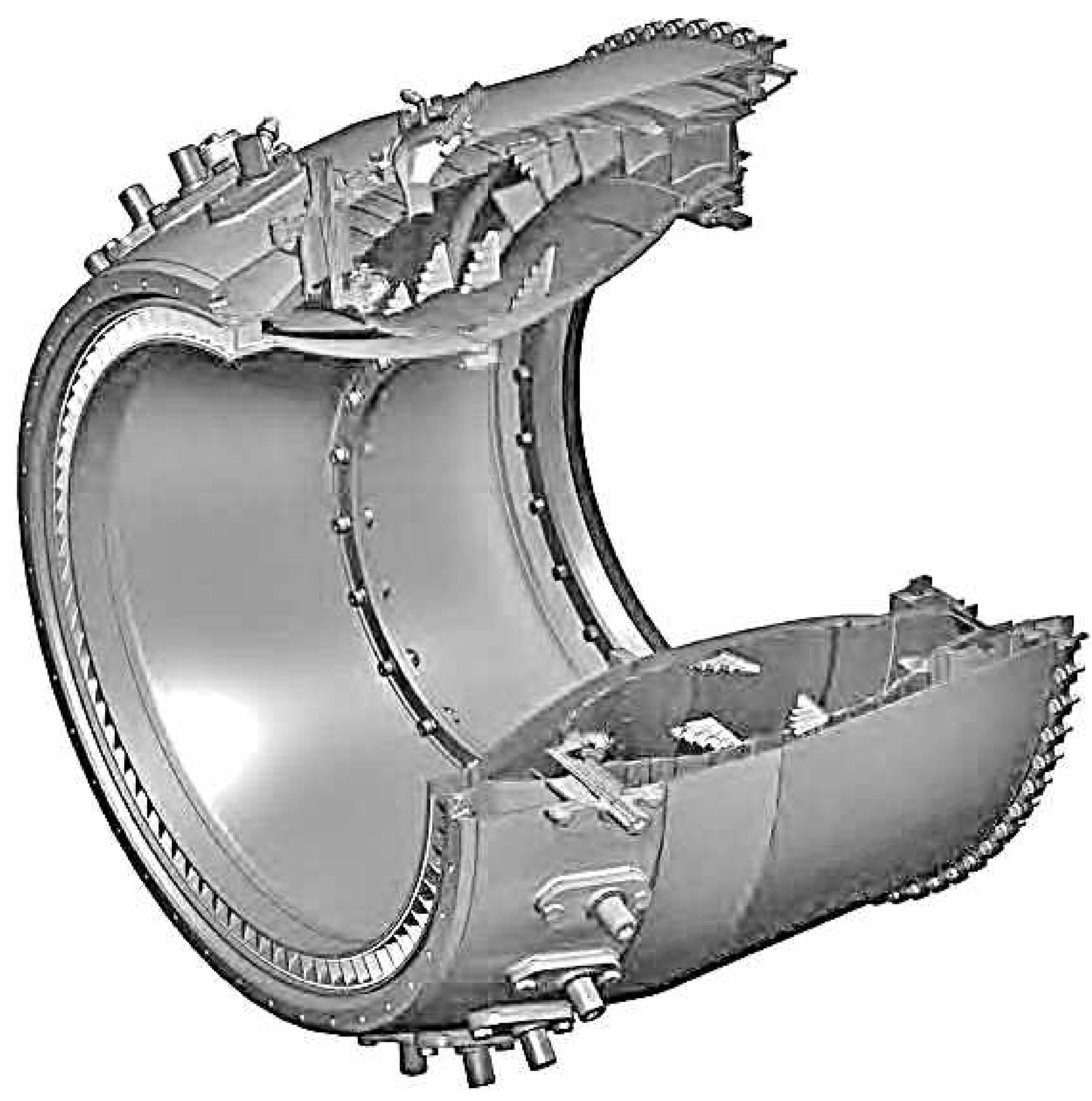

Figure 4.1 – Combustion chamber (section of the solid model)

A high-pressure compressor casing is attached to the chamber from the front; nozzle vanes and a high-pressure turbine casing are attached behind it.

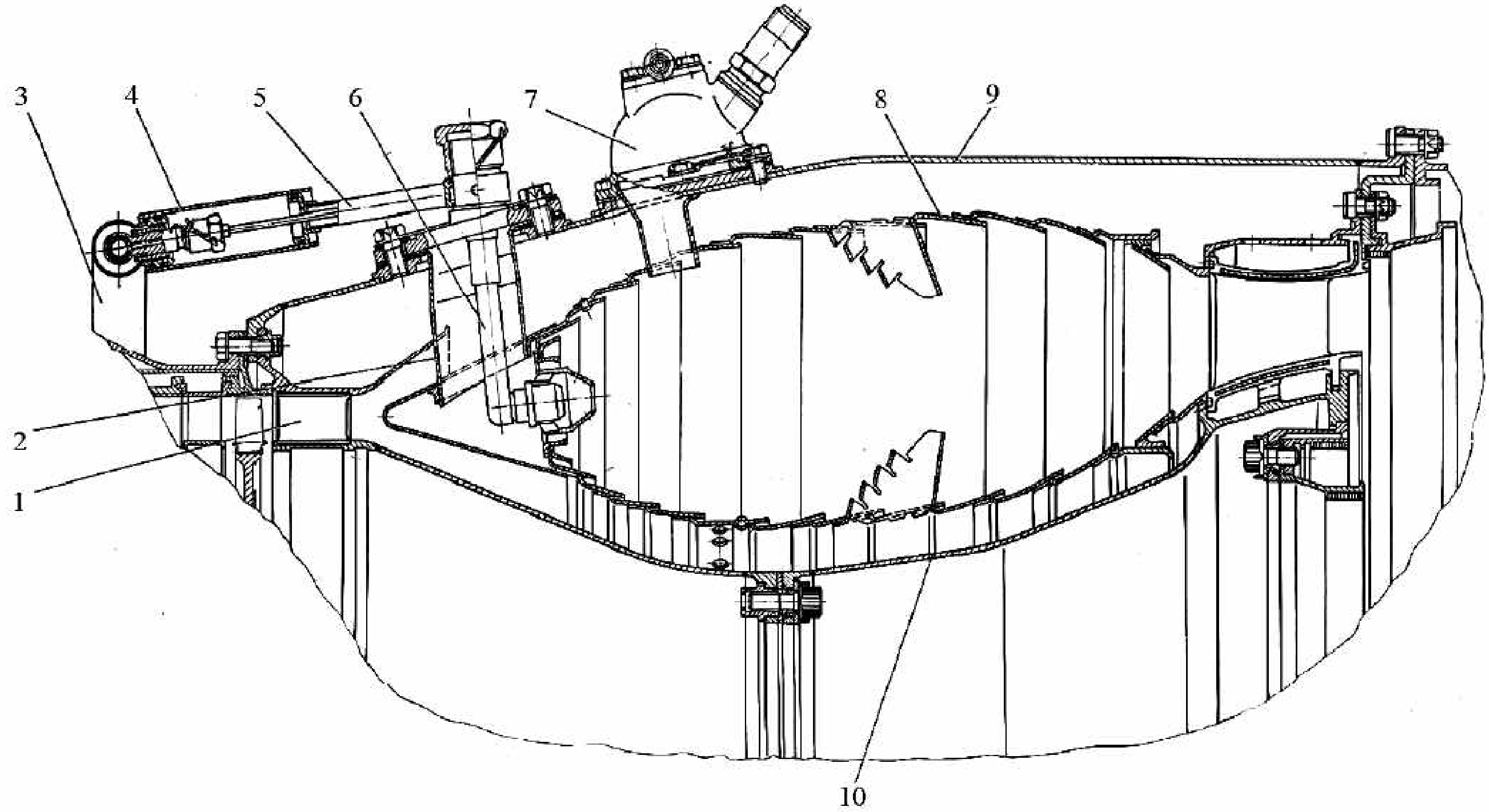


Figure 4.2 – Combustion chamber:
1 – diffuser with straightening vanes of a HPC last stage; 2 – hollow bushing; 3 – a fuel manifold; 4 – the bushing; 5 – a pipe of a fuel supply from a manifold to spray nozzles; 6 – spray nozzle; 7 – pilot igniter; 8 – a flame tube; 9 – housing; 10 – inner casing of the HPT nozzle vanes

The front section of the combustion chamber air path is made in the shape of diffuser channels formed by the cone of the flame tube and the shells of the diffuser. In the diffuser channels, the speed of the air flow coming from the compressor decreases. From the diffuser channels, air enters the outer and inner annular channels, from which by the holes and nozzles in the flame tube is distributed into its primary and secondary zones. In addition, a significant part of the primary air from the central part of the initial section of the air path through the holes enters the cavity of the fairing of the flame tube.

# 5 TURBINE

## 5.1 General Information

*The engine turbine* (Figure 5.1), designed to convert the gas stream energy into mechanical one and transfer it to the compressors shafts and to the components drive consists of a high pressure turbine (HPT), low pressure turbine (LPT) and a fan turbine (FT).

*High pressure turbine* is axial, single-stage, converts heat drop into mechanical work, going to the high-pressure compressor and components drive.

*The low pressure turbine* is axial, single-stage, converts heat drop into mechanical work, going to drive the low-pressure compressor.

*The fan turbine* is axial, three-stage, and converts heat drop into mechanical work, going to the fan drive.

## 5.2 High Pressure Turbine

The high-pressure turbine includes a stator and a rotor.

The stator (Figure 5.2) consists of a nozzle guide vanes, including an outer casing 1, an inner casing 11, seven sectors 6 and one nozzle vane between them, a rear casing 4, ten spacers 1 of stage 5, rings 7 and 8 with honeycomb elements of a labyrinth seal.

The nozzle guide vanes 3 (see Figure 5.1) are fastened with thirty bolts 1 to the conical beam of the combustion chamber, with eighty bolts 4 to the combustion chamber casing and the casing of the turbine supports 5. It serves to supply gas to the HP turbine rotor blades, centering the outer and inner rings of the combustion chamber flame section and supply air for cooling the turbine rotor blades.

Between the outer 1 (see Figure 5.2) and the inner 11 housings there are seven sectors, each consisting of four vanes, and one vane, i.e. a total of 29 vanes are located around the circumference.

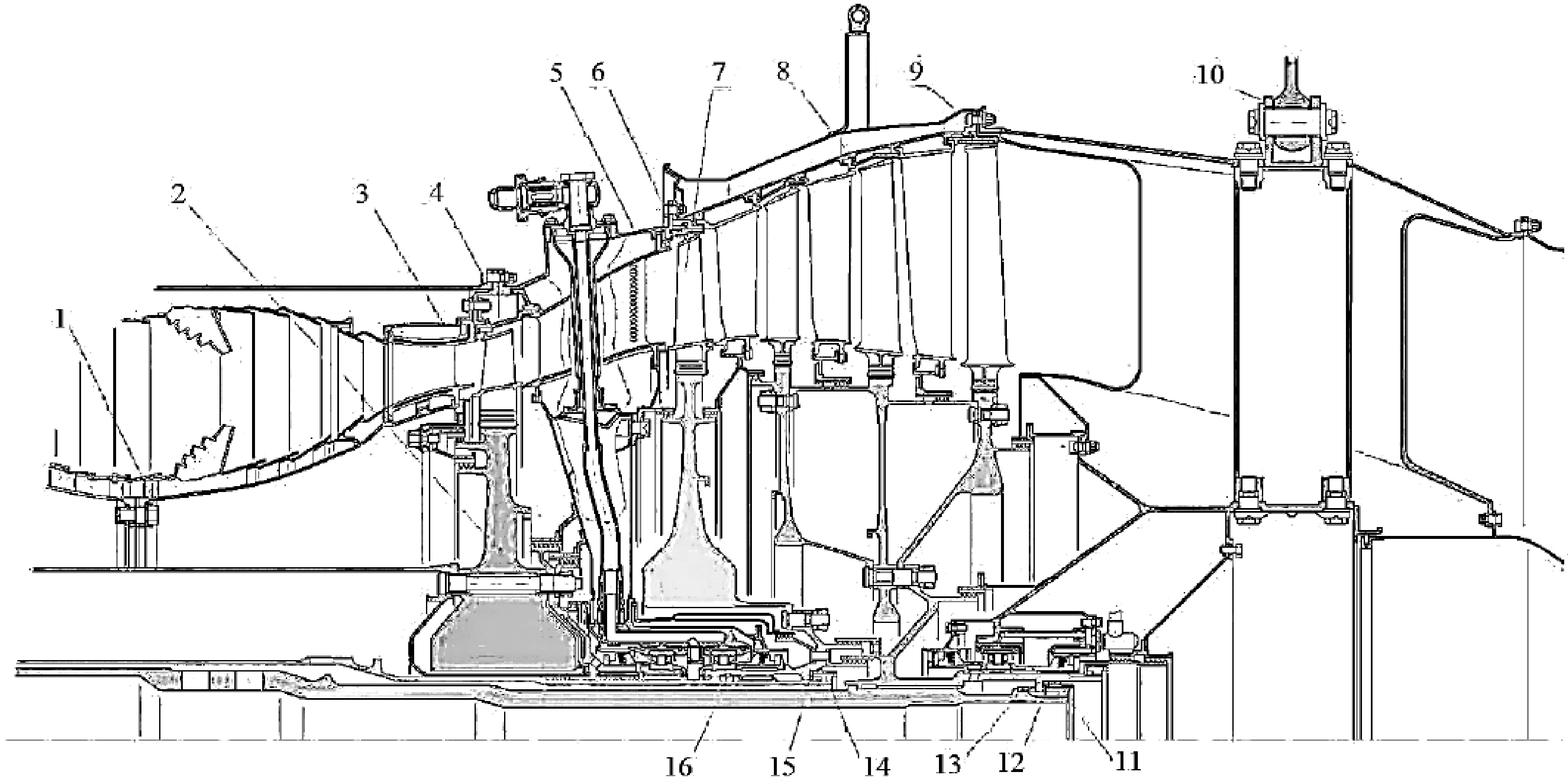


Figure 5.1 – Turbine:
1,4,6,9 – bolts; 2 – HPT rotor; 3 – HPT nozzle unit; 5 – the housing of turbines supports; 7 – LPT rotor; 8 – the fan turbine; 10 – back support with outlet cone and nozzle; 11 – a FT shaft nut; 12,15 – washers; 13.16 – the adjusting ring; 14 – a LPT shaft nut

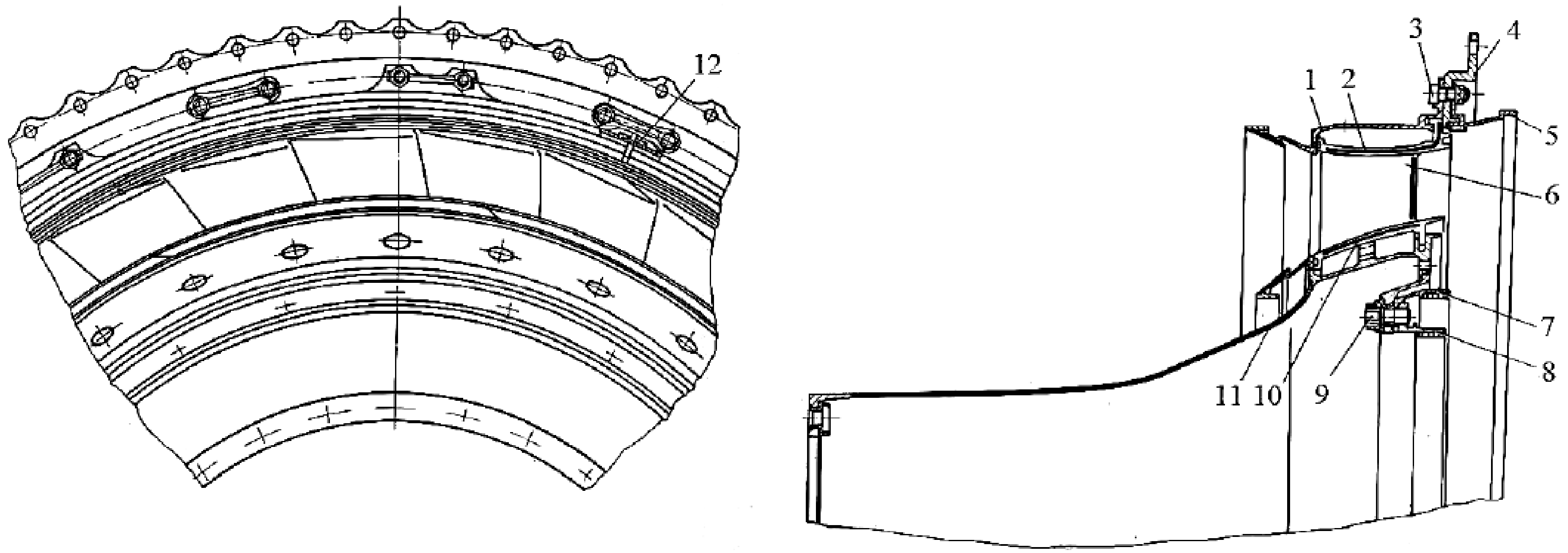


Figure 5.2 – HPT stator:
1 – outer case; 2 – outer sealing plate; 3, 9 – bolts; 4 – rear case; 5 – spacers of the 1st stage; 6 – sector of blades, nozzle vanes; 7 – outer ring; 8 – inner ring; 10 – inner sealing plate; 11 – inner case; 12 – sealing plate

Inside each blade (Figures 5.3 and 5.4) a deflector 2 is rolled up, which serves to pressurize the cooling air to the blade walls. The collar 3, located on the lower flange of the sector, serves for axial fixation, and the ledge 4 - for fixing the sector in the circumferential direction.

To ensure the tightness of the joints between sectors 6 (see Figure 5.2) of the nozzle vanes, sealing plates are installed: outer 2 and inner 10.

To the outer casing 1 the rear casing 4 and ten spacers 1 of stage 5 with honeycomb elements of the labyrinth seal are attached with forty bolts 3.

To ensure the tightness of the joints between the spacers, ten sealing plates 12 are installed.

The outer 7 and inner 8 rings are attached with twenty-four bolts 9 to the flange of the inner housing 11.

Figure 5.3 – HPT nozzle vanes sector (solid model)

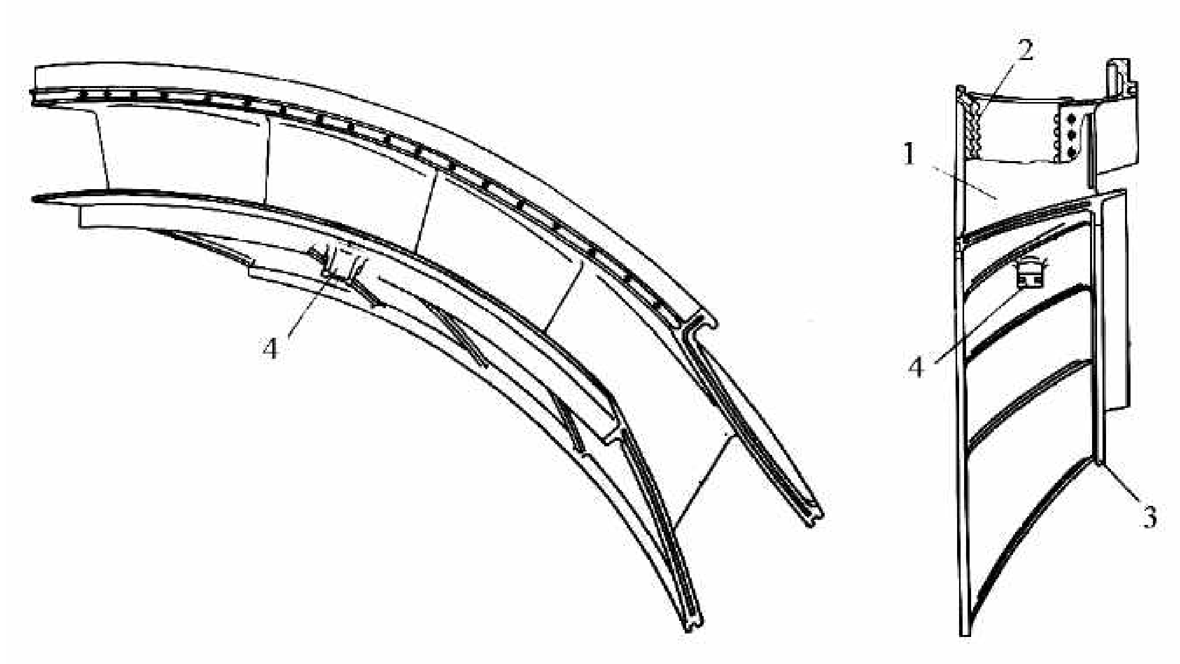


Figure 5.4 – Sector of HPT nozzle vanes: 1 – vane; 2 – deflector; 3 – collar; 4 – ledge

The HPT rotor (Figures 5.5 and 5.6) consists of an impeller 5, a rear shaft 15 with labyrinth seal combs, parts 1, 2, 3, 4, 19 of an air-tight seal, a roller bearing 17, nuts 11 and tie bolts 12 for fastening the shafts to the impeller 5, nuts 18 for fastening the roller bearing 17 on the rear shaft 15, parts 14, 20, sealing the cavity formed by the hub part of the impeller disk and the screen.

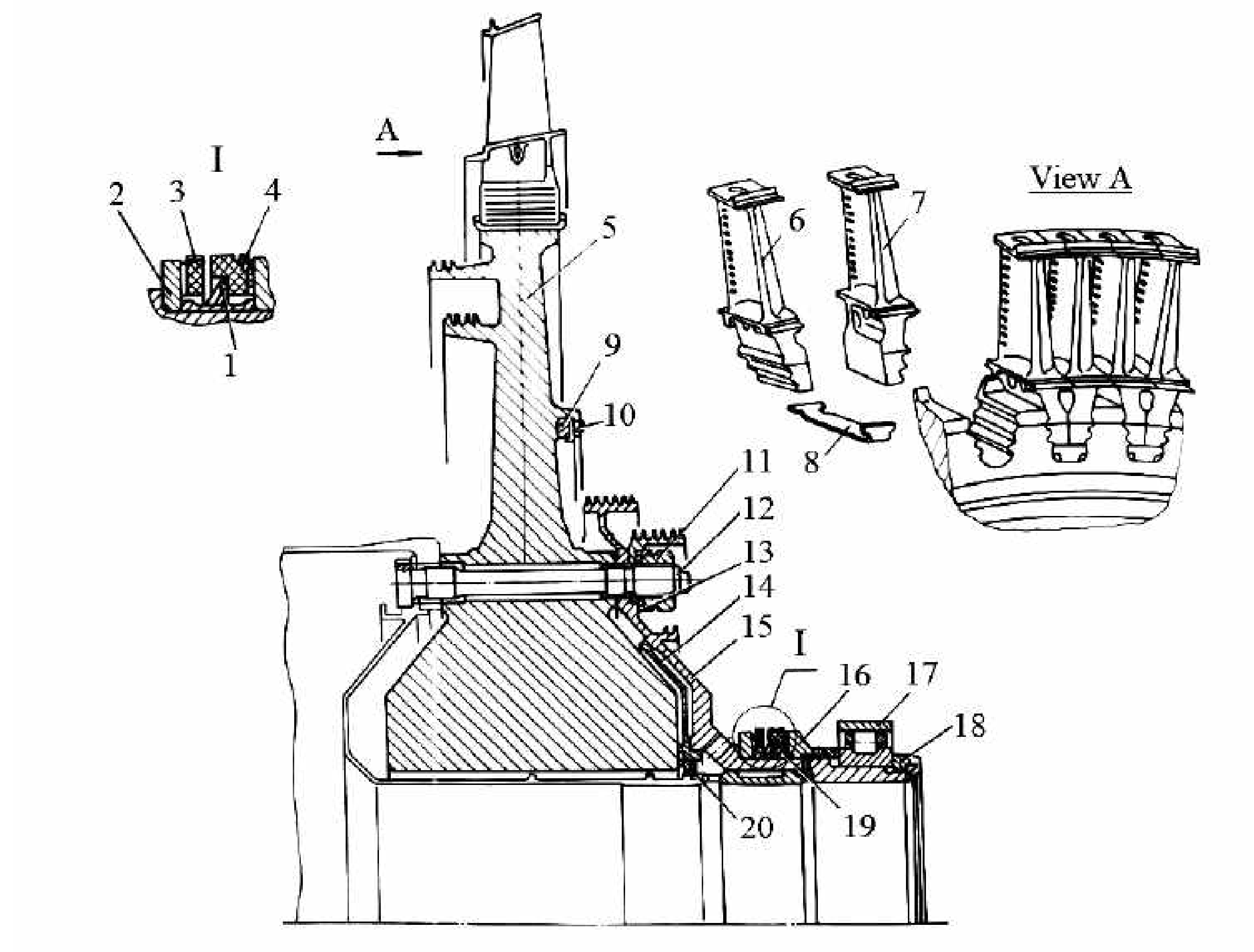


Figure 5.5 – HPT rotor:
I – spring; 2.16 – persistent rings; 3 – ring; 4 – a sealing ring; 5 – impeller; 6 – working blade (right); 7 – working blade (left); 8 – counter; 9 – balancing weight; 10 – lock; 11, 18 – nuts; 12 – coupling bolt; 13 – locking washer; 14 – screen; 15 – rear shaft; 17 – roller bearing; 19 – bushing; 20 – sealing ring

Rotor 2 (see Figure 5.1) is fastened to the high-pressure compressor shaft with sixteen bolts, and the outer ring of the roller bearing of the HPT rotor is mounted in the housing 5 of the turbine supports.

The impeller 5 (see Figure 5.5) consists of a disk with 59 fir-tree grooves, into which 59 pairs (right 6 and left 7) of blades are installed, fixed in the axial direction with locks 8.

The turbine disk has two labyrinth collars on the inlet side, a balancing weight attachment collar 9 on the outlet side and sixteen bosses with holes for tie bolts on each side.

Figure 5.6 – HPT rotor (solid model)

The rotor blades (left and right Figure 5.7) consist of an upper shroud, an airfoil body, a lower shroud, a root and a lock. A labyrinth seal comb is made on the upper shroud of the blades to reduce gas overflow over the impeller. On the outer surface of the shelf there are channels that supply air to cool the blade. The lower shroud at the front and rear has ledges for overlapping the axial gaps between the rotor and the stator in order to reduce the circulation of hot gas in the interdisk cavity and to reduce cooling air leaks.

The blade root acts as a thermal resistance, which reduces the heating of the disc rim. The lower shrouds and roots of each pair of blades form a cavity for supplying cooling air to the channels of the airfoil body of the blades. On the outlet side, a ledge on the rim of the disc closes the cavity. The high-pressure compressor shaft and the rear shaft 15 are connected to the impeller 5 by sixteen tie bolts 12, the conical fit sections of which serve to center the impeller relative to the shafts and transmit the torque: the nuts 11 of the tie bolts are fixed from the turning away with lock washers 13.

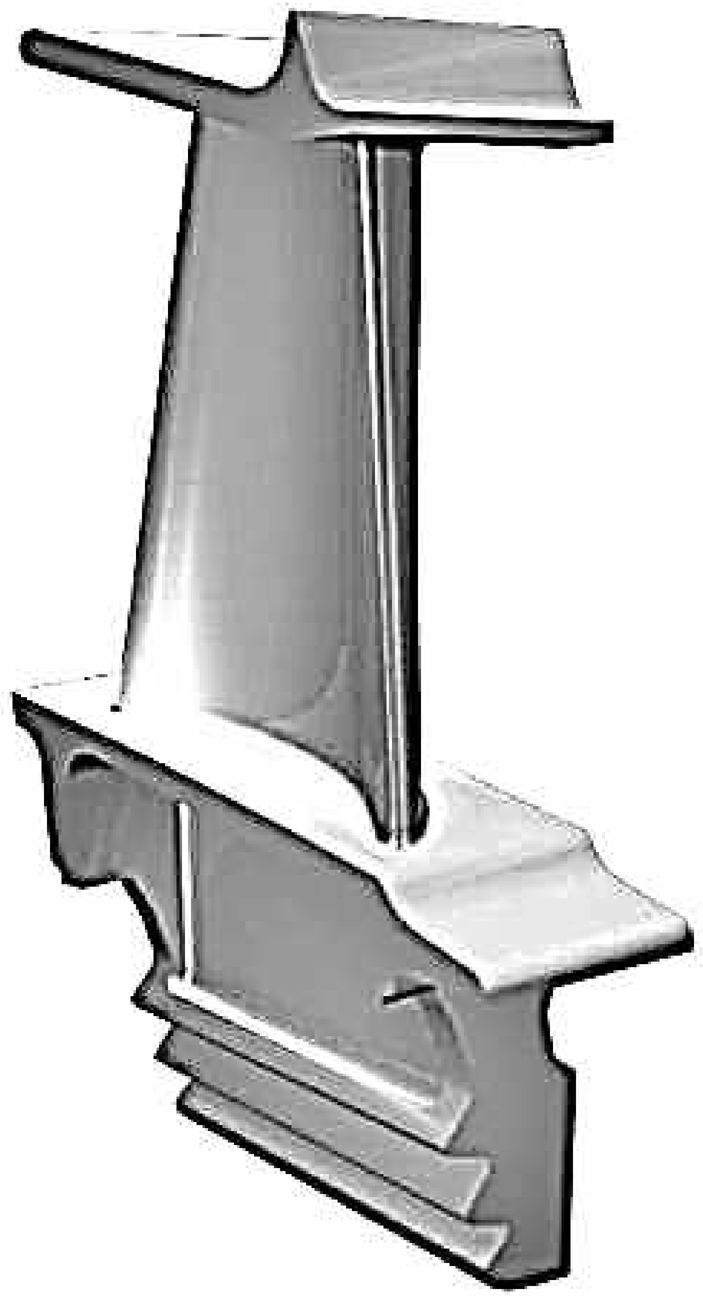

Figure 5.7 – HPT rotor blade (solid model)

A groove is made on the cylindrical part of the screen, in which the sealing ring 20 is mounted.

The rear shaft 15 is tapered with shoulders carrying labyrinth seal ridges. On the shaft from the side of the turbine disk, a screen 14 is installed, which reduces the heat transfer from the disk to the shaft

The turbine rotor is balanced by means of weights 9, which are installed in the groove under the disc shoulder from the outlet side and are fixed in the circumferential and radial directions with locks 10.

### 5.3 Low Pressure Turbine

A low-pressure turbine (LPT, Figure 5.8) includes a stator and a rotor.

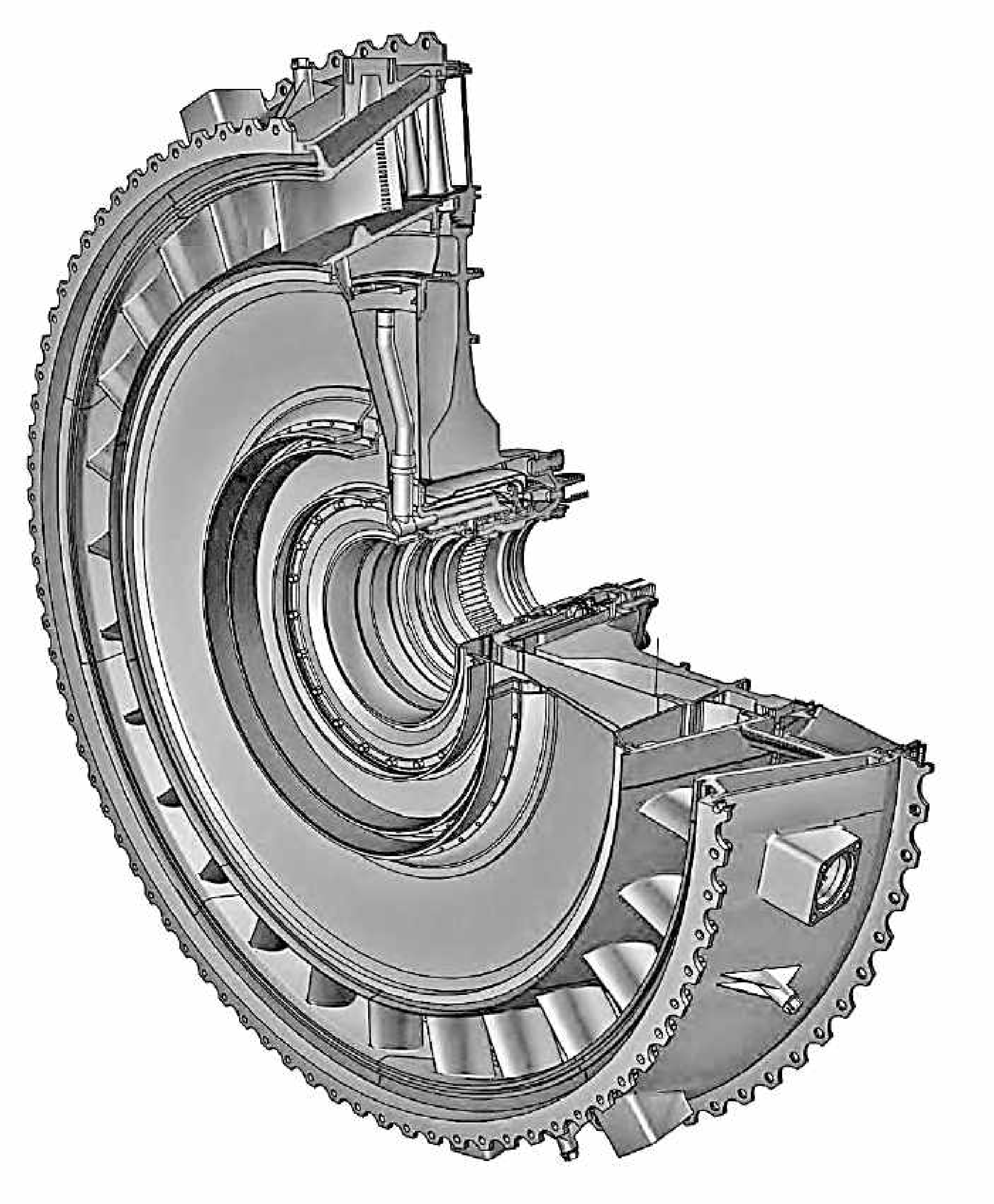

Figure 5.8 – Low-pressure turbine (section of the solid model)

The stator (Figures 5.9 and 5.10) consists of a turbine support housing, including an outer 21 and an inner 16 housings, interconnected by means of nine bolts 22 and fit bushings 23, and nine sectors 20 of the blades of the II stage nozzle guide vanes mounted between these housings.

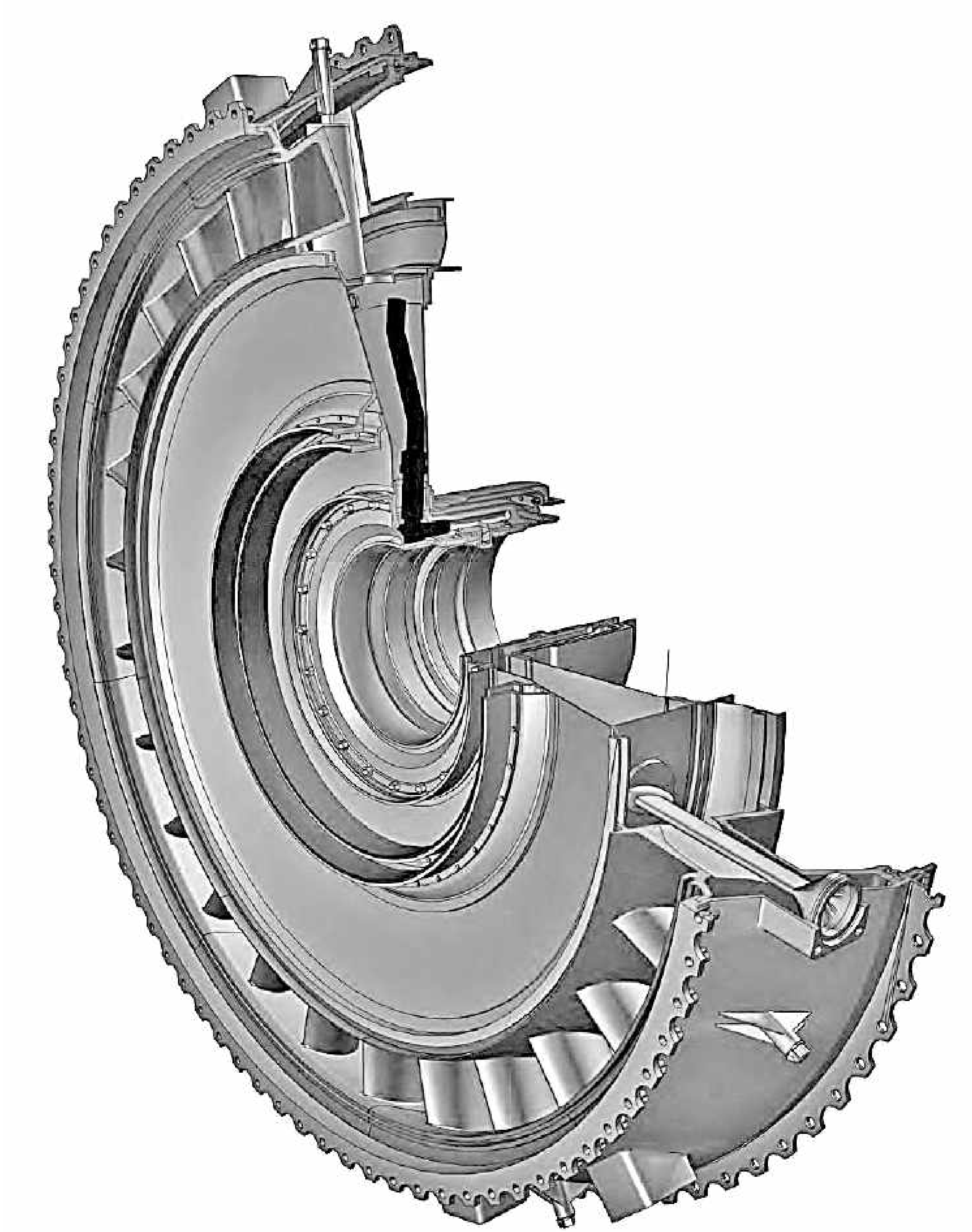

Figure 5.9 – Turbine support casing (section of the solid model)

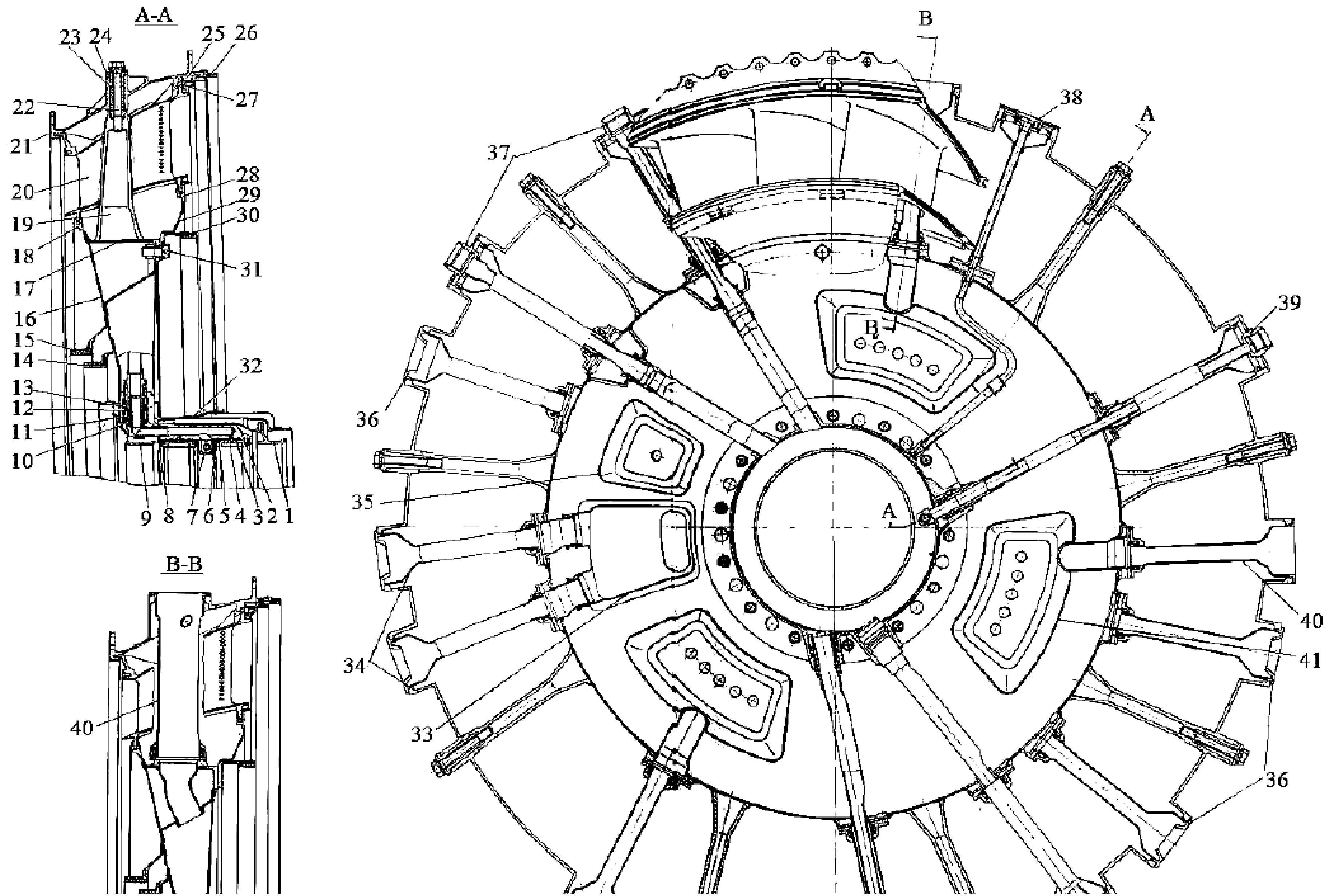


Figure 5.10 – Turbine support housing

Legend in Figure 5.10:

1 – rear sealing ring; 2 – bearing housing; 3 – right ring; 4 – outer ring of the roller bearing; 5 – left ring; 6 – oil sealing ring; 7 – oil nozzle; 8 – bushing; 9 – front sealing ring; 10 – adapter; 11 – nut; 12 – ring; 13 – a sealing ring; 14, 15, 30 – rings with honeycomb elements of the labyrinth seal; 16 – inner case; 17 – power cylinder; 18 – fixing ring; 19 – strut; 20 – sector of the nozzle vanes of the II stage; 21 – outer case; 22, 31, 43 – bolts; 23 – close fitting sleeve; 24 – locking washer; 25 – pin; 26 – stage II spacer; 27 – segment; 28 – flange; 29 – inner ring; 32 – casing; 33, 35, 41 – pockets; 34 – pipe for venting the intermediate cavity; 36 – pipe for air supply for cooling of the bearing housing; 37 – pipe for venting the oil cavity; 38 – air bleed pipe; 39 – oil supply pipe; 40 – casing for air supply for cooling the rotors of HPT, LPT, FT; 42 – oil scavenging pipe.

The housing of the turbine supports 5 (see Figure 5.1) with eighty bolts 4, ten of which are tight-fitting, is attached to the power casing of the combustion chamber, the fan turbine stator is attached to the rear flange using eighty bolts 6, ten of which are tight-fitting.

On the housing of the turbine supports (see Figure 5.10) are installed: front sealing ring 9 with bolts 43, casing 32, oil nozzle 7, outer rings 4 of roller bearings; rings 3 (right) and rings 5 (left), O-rings 6 of the oil damper, bushing 8, adapter 10 for supplying oil for lubrication and cooling of bearings and for oil dampers, elements of seals for pipelines for oil supplying and scavenging, nut 11, ring 12, O-ring 13; inner ring 29 - with bolts 3.

On the outer casing 21 of the housing of the turbine supports are located: a flange of the pipe 39 for supplying oil to the supports and oil dampers of the HPT and LPT rotors, two flanges of the tubes 37 for venting the oil cavity, two flanges of the tubes 34 for venting the intermediate cavity, three flanges of the casings 40 for air supply for cooling the rotors of the HPT and LPT, three flanges of the pipes 36 for supplying air for cooling the bearing housing, a flange of the air bleed pipe 38, two flanges 42 of the oil scavenging pipes, as well as nine bosses for securing the struts 19. The outer case has a groove in front for radial fixation of the LPT nozzle vanes sector, at the back - a groove for mounting segments 27 and a groove with pressed-in pins 25 for circumferential fixation of the II stage spacers, as well as nine protrusions for circumferential fixation of the sectors of the nozzle guide vanes.

The inner housing 16 of the housing of the turbine supports is of a welded structure, consists of a bearing housing 2, load-bearing walls and a power cylinder 17, a retaining ring 18 and a rear flange for fastening the inner ring 29, nine struts 19 welded between the load-bearing walls of the pockets 33, 35, 41, sealing ring 1 and rings 14, 15 with honeycomb elements of the labyrinth seal.

The inner ring 29 is a welded structure, contains an O-ring 30 with honeycomb elements of a labyrinth seal, a cone and a flange 28 with a retaining groove.

Between the outer casing 21 and the inner casing 16 are located nine sectors 20 of the II stage nozzle guide vanes (Figures 5.11 and 5.12), intended for supplying gas to the working blades of the low-pressure turbine.

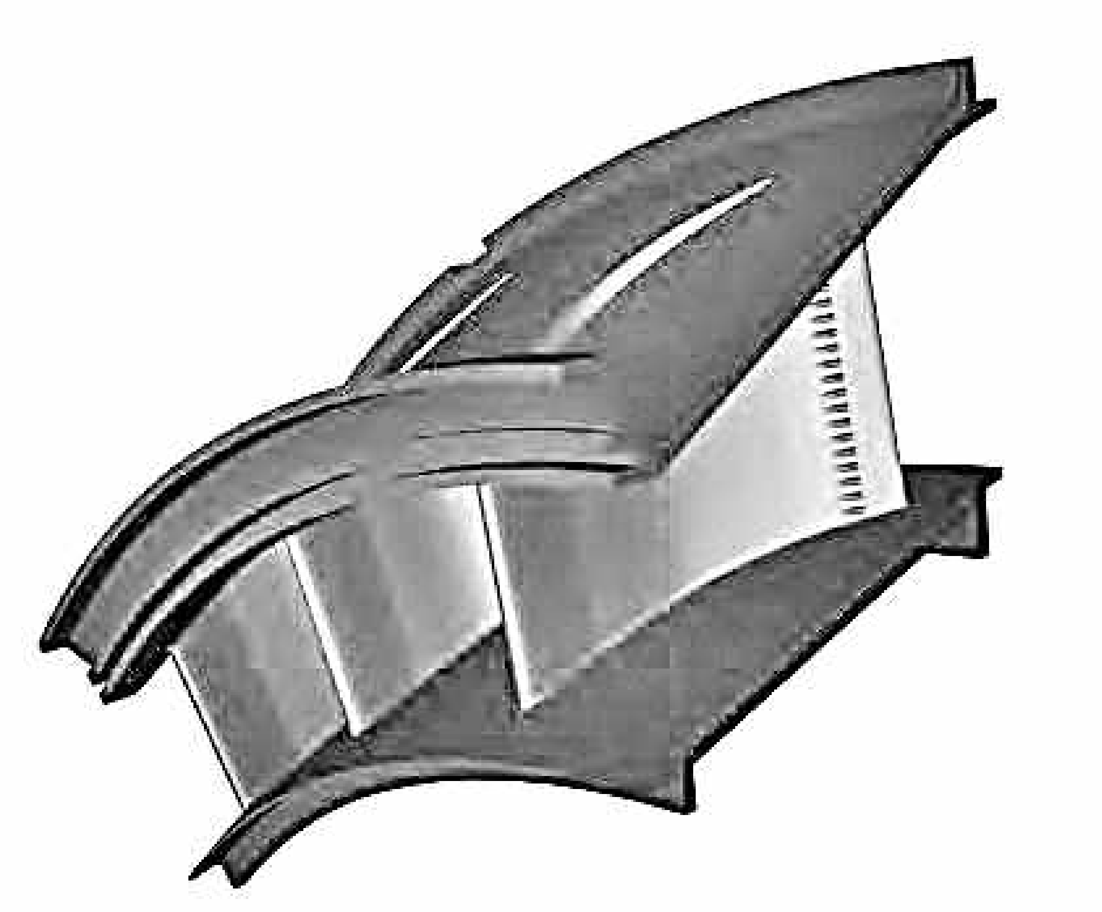

Figure 5.11 – Sector of the turbine II stage guide vanes (solid model)

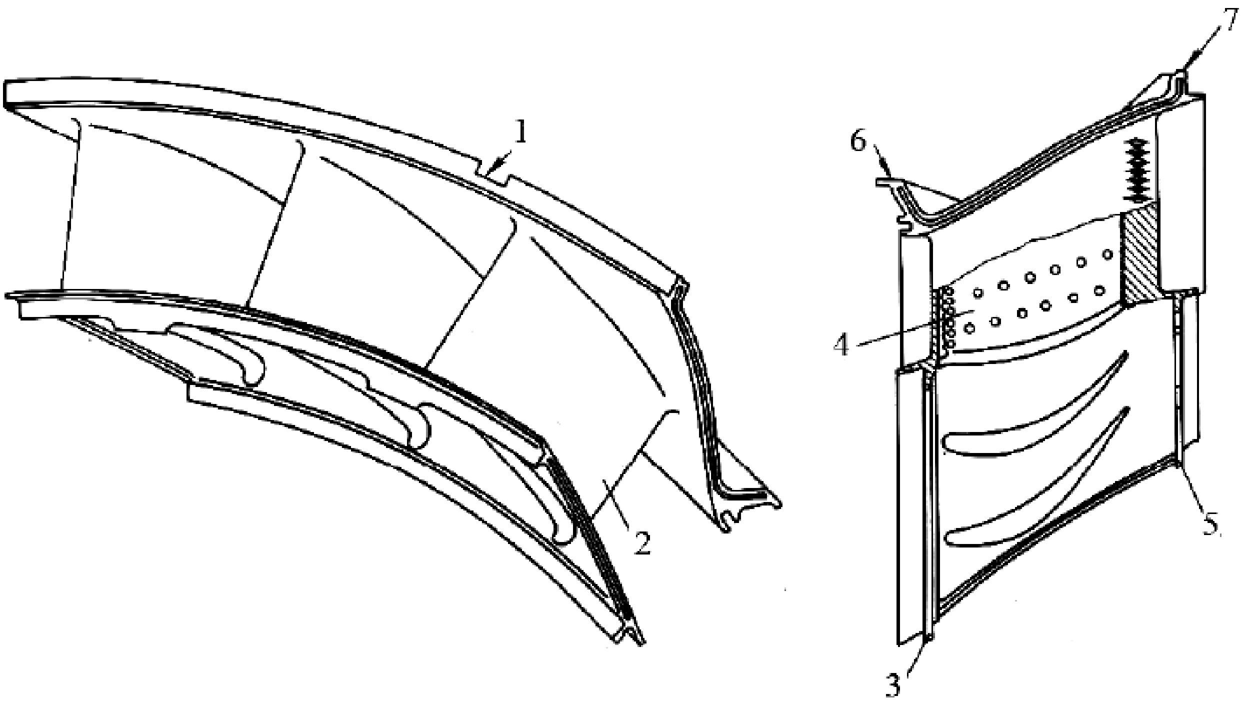


Figure 5.12 – Sector of the turbine II stage nozzle guide vanes:
1 – groove; 2 – nozzle vane; 3, 5 – collars; 4 – deflector; 6 – belt; 7 – support belt

Axial fixation of the sectors of the nozzle guide vanes of the II stage is carried out by flanges 3 and 5 (see Figure 5.12), entering the corresponding grooves of the housing 16 (see Figure 5.10) and the inner ring 29, and by segments 27; radial fixation - with a collar 6, which is included in the corresponding groove of the outer casing 21, and a supporting collar 7 (see Figure 5.12), and circumferential fixation - with protrusions in the outer casing that enter the grooves 1 of each sector of the nozzle guide vanes of the II stage.

The sector of the nozzle guide vanes of the II stage (see Figures 5.11 and 5.12) consists of three hollow blades 2 with a deflector 4, similar to the deflectors of the blades of the HPT nozzle apparatus.

The air for cooling the blades is supplied through pipes 40 (see Figure 5.10) for supplying air for cooling the rotors of the HPT, LPT, FT.

The sectors of the vanes on the side surfaces of the shrouds have grooves in which sealing plates are installed to create a tightness of the joints between the sectors.

The ends of the outer and inner flanges are used to bridge the axial clearances in order to reduce the circulation of hot gases.

The LPT rotor section (of the solid model) and fastening the blade to the disc are presented on Figures 5.13 and 5.14.

The LPT rotor (Figure 5.15) consists of an impeller 1, a shaft 9, a roller bearing 12 LPT, a sleeve 10, a thrust ring 11, bolts 6 and nuts 8 for fastening the shaft to the impeller, a nut 13 for fastening a roller bearing and parts of an airtight seal on the shaft, labyrinth seal rings.

The rotor 7 of the LPT (see Figure 5.1) is mounted in the housing 5 of the turbine supports and transmits the torque to the low-pressure compressor shaft using a spline connection; the required axial position of the rotor of the LPT relative to the stator is regulated by ring 16.

The impeller (see Figure 5.15) consists of a disk and 122 rotor blades 2, installed in the fir-tree grooves of the disk and fixed in the axial direction by lamellar locks 3.

The turbine disk has labyrinth collars on the inlet and outlet sides, a collar for fastening balancing weights 4 and a flange with eight holes for bolts 6 for fastening the shaft 9.

The bottom shroud has protrusions at the front and rear to cover the axial clearances between the rotor and the stator. The blade root plays the role of thermal resistance, which reduces the heating of the disc rim and prevents gas flow in the axial direction.

The shaft 9 is attached to the impeller by eight bolts 6, the conical fit sections of which are used to center the impeller relative to the shaft and transmit the torque, and by nuts 8, which are fixed from unscrewing with washers 7.

The involute splines of the shaft 9 are used to transmit torque from the impeller of the LPT rotor to the rotor of the low pressure compressor.

The rotor of the LPT is balanced using weights 4, which are fixed in the circumferential and axial directions with locks 5.

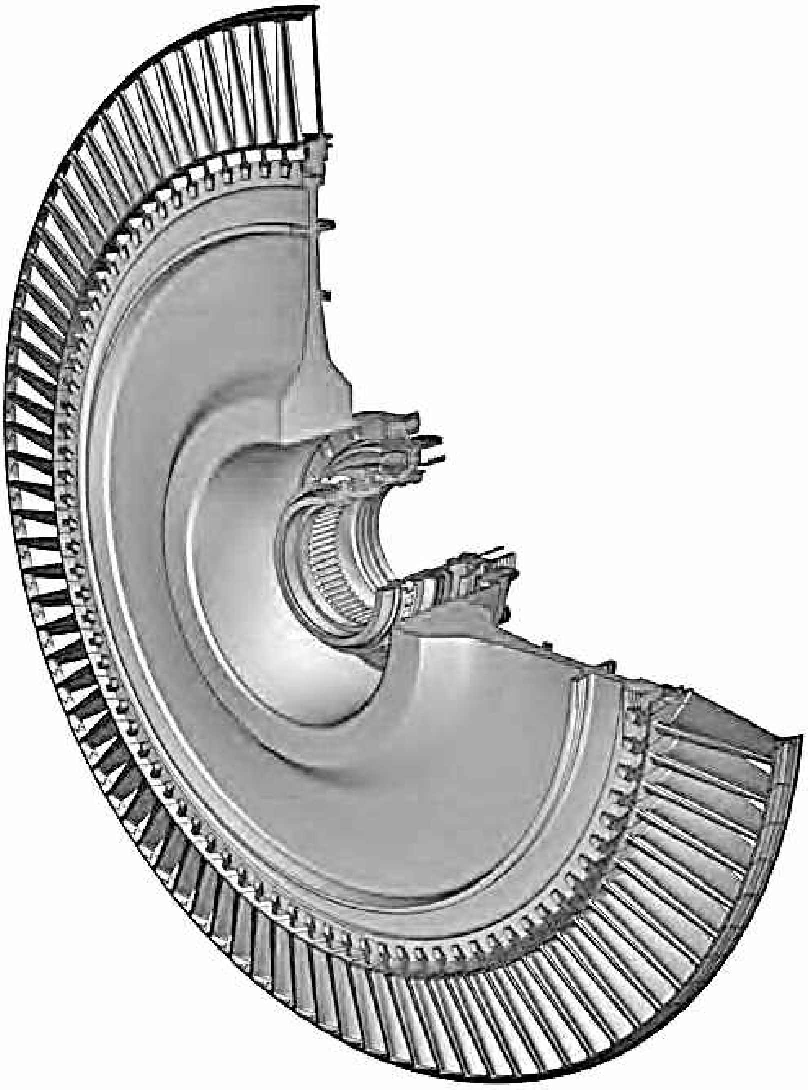

Figure 5.13 – LPT rotor (section of the solid model)

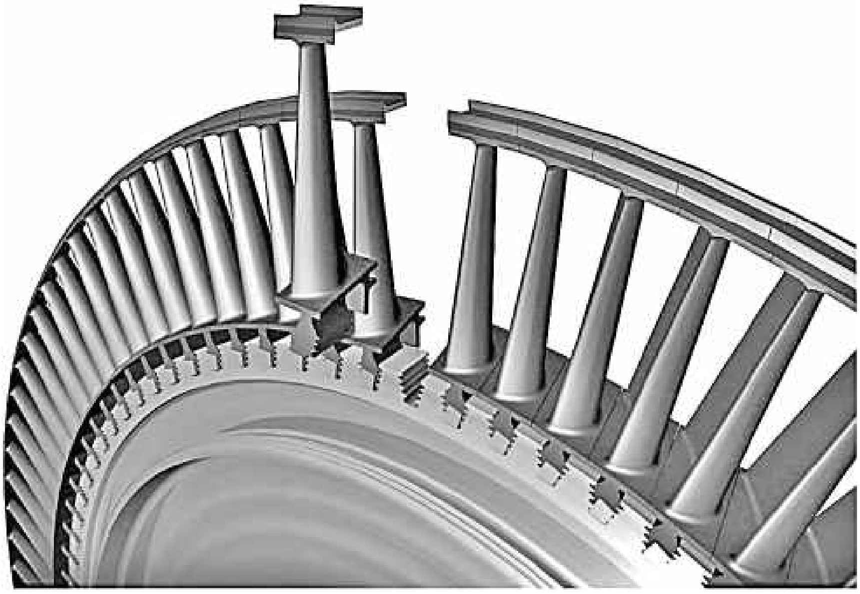

Figure 5.14 – Fastening the blade to the disc

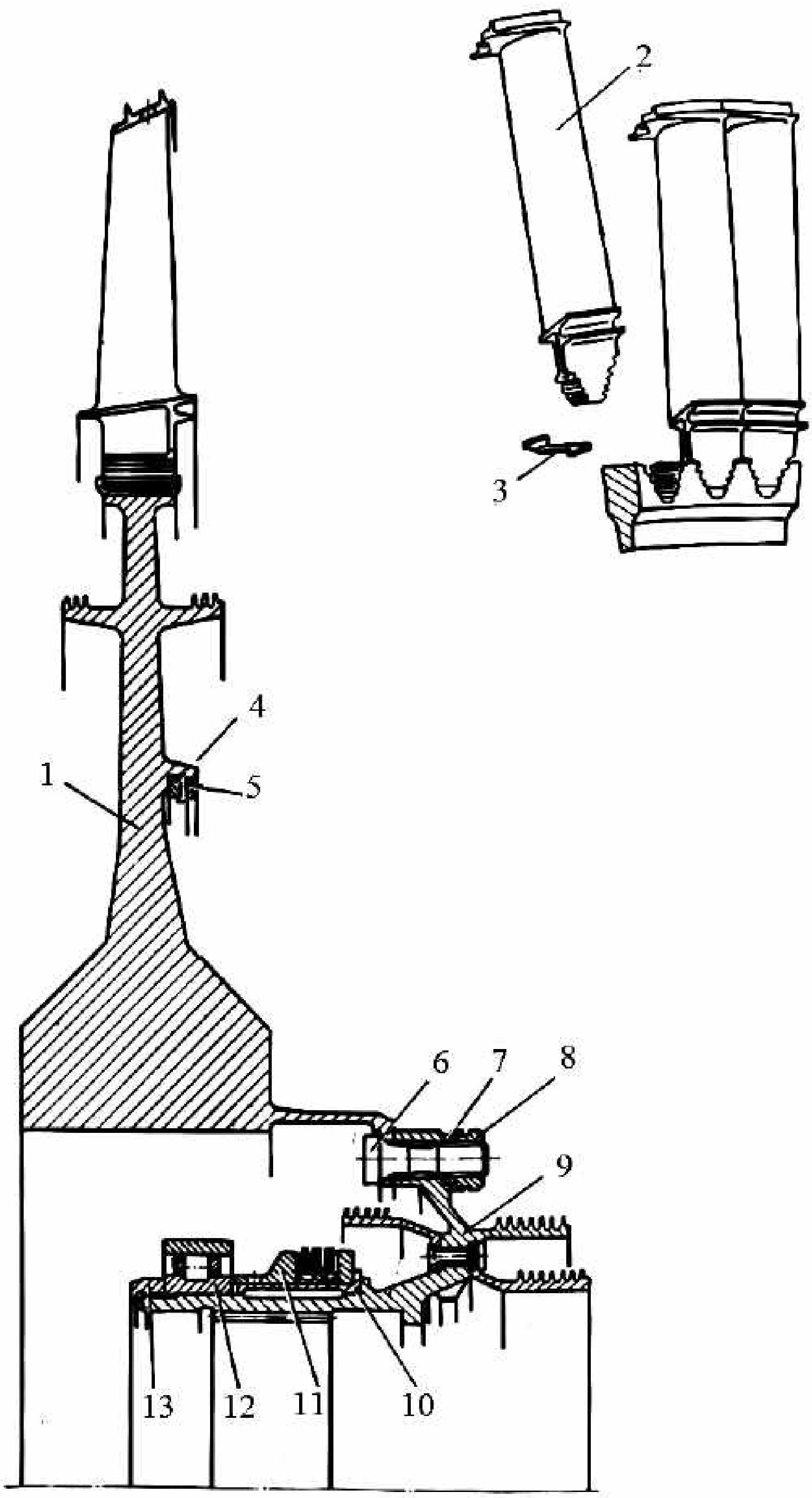


Figure 5.15 – LPT rotor:
1 – impeller; 2 – working blade; 3 – plate lock; 4 – balancing weight; 5 – lock; 6 – bolt; 7 – washer; 8, 13 – nuts; 9 – shaft; 10 – bushing; 11 – thrust ring; 12 – roller bearing

## 5.4 Fan Turbine

The fan turbine (FT, Figures 5.16 and 5.17) consists of stator 1 and rotor 2 (see Figure 5.17).

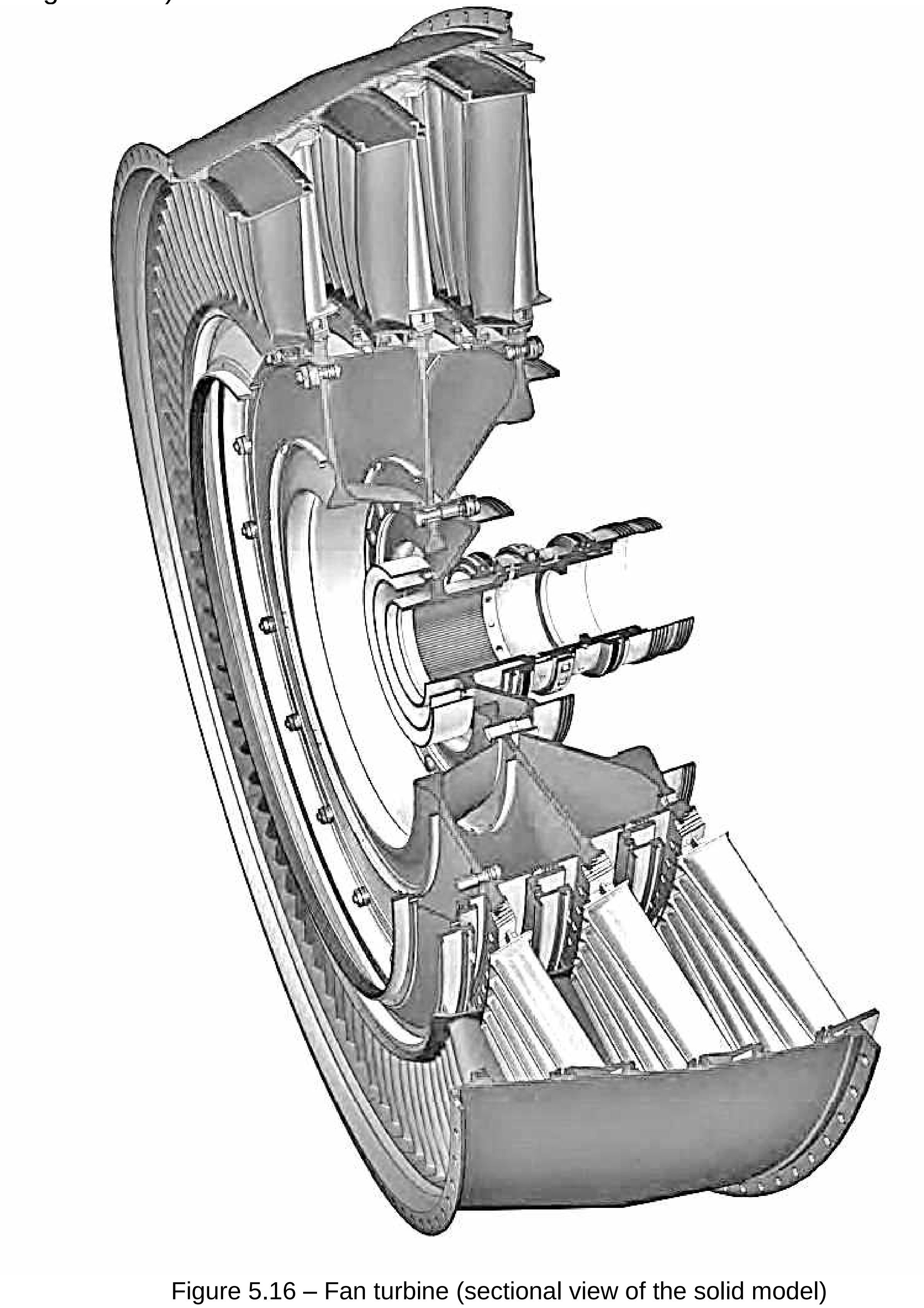

Figure 5.16 – Fan turbine (sectional view of the solid model)

The stator of the fan turbine (see Figure 5.1) is attached to the housing of the turbine supports 5 by eighty bolts, of which ten are tight, and seventy are screwed into self-locking nuts pressed into the front flange. The rear support 10 is attached to the rear flange of the fan turbine stator by means of ninety bolts, ten of which are tight-fitting.

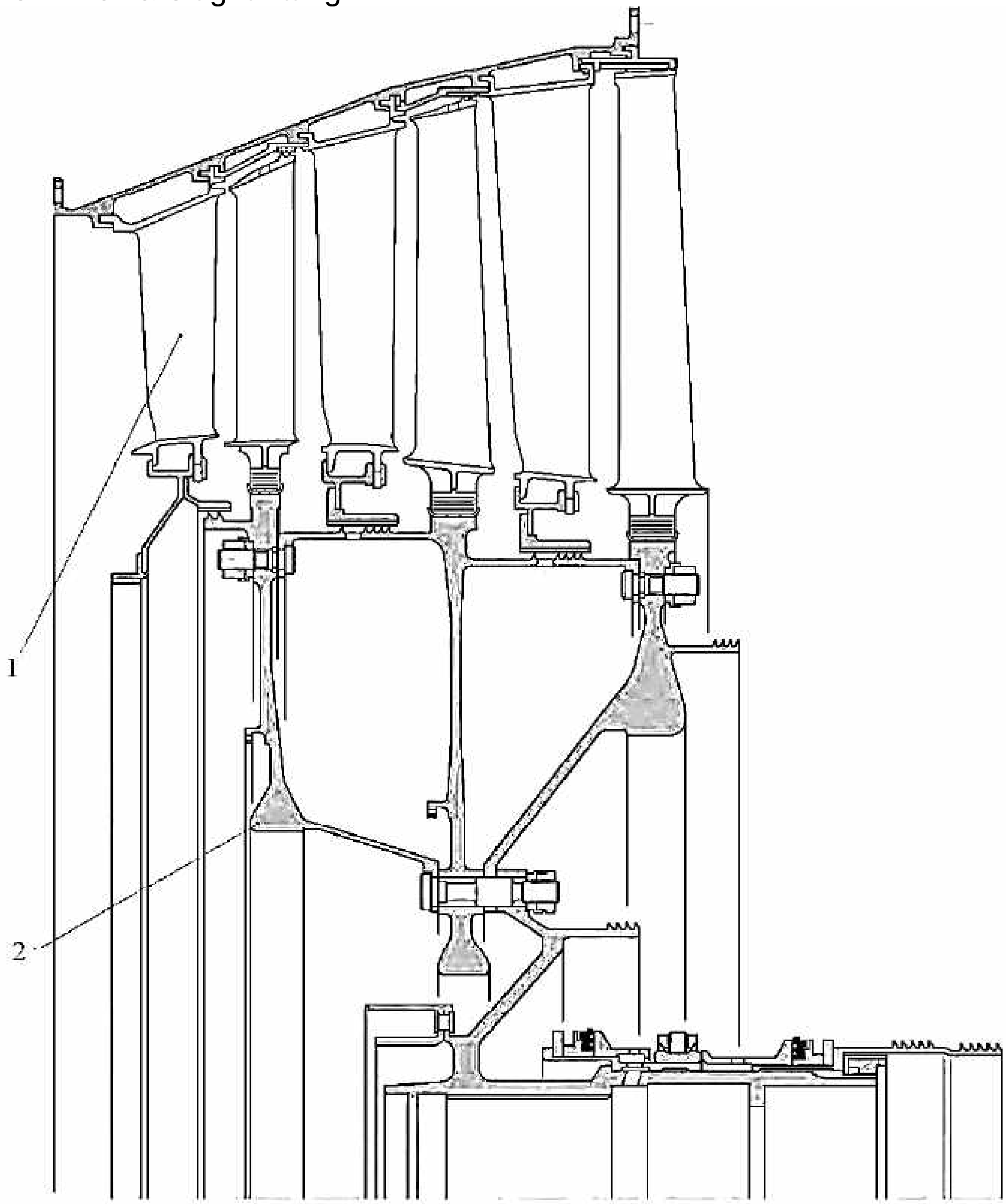


Figure 5.17 – Fan turbine: 1 – stator; 2 – rotor

The FT rotor (see Figure 5.1) is mounted in the rear support 10 with its own bearing. In is connected with the splines with the fan shaft and tightened with a nut 11 with a washer 12. The required axial position of the FT rotor relative to the stator is adjusted by ring 13.

The stator (Figures 5.18 and 5.19) of the fan turbine consists of an outer casing 6, nineteen sectors 2 of nozzle vanes of the III stage, nineteen sectors 8 of nozzle vanes of the IV stage, twenty-one sectors 10 of nozzle vanes of the V stage, inner casings 1, 13, 12 of nozzle vanes of III, IV, V stages, respectively, and spacers (5, 9, 11) of III, IV, V stages.

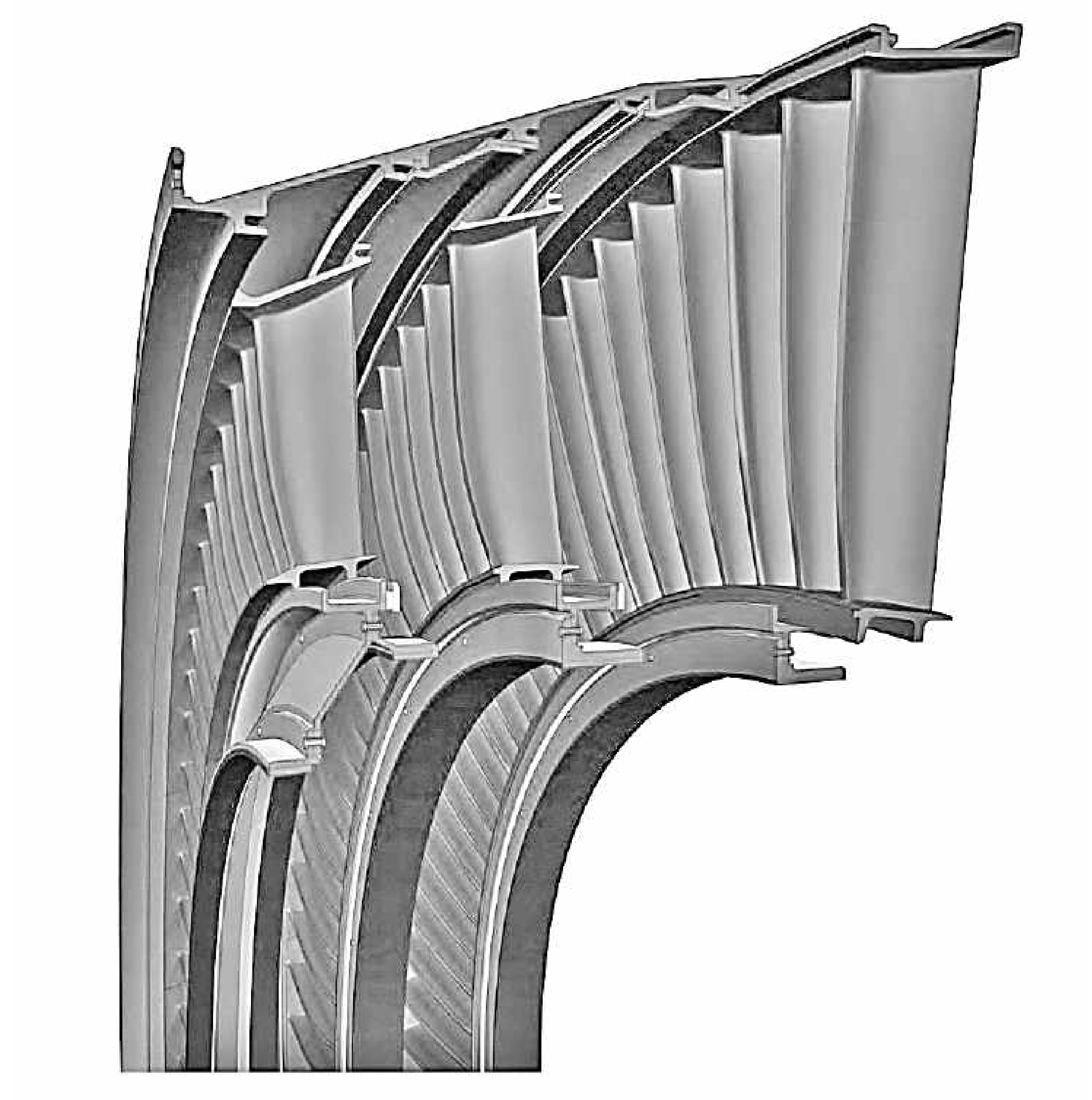

Figure 5.18 – Stator of the fan turbine (section of the solid model)

On the outer casing 6 there are seventeen flanges for fixing thermocouples, six flanges with windows for inspection of working blades of FT and LPT, closed with plugs 7 and bosses for attaching the thermocouple electric collector and the casing. Inside the outer casing, ribs with grooves are made for fastening sectors 2, 8, 10 of the nozzle guide vanes of the FT and spacers 5, 9, 11.

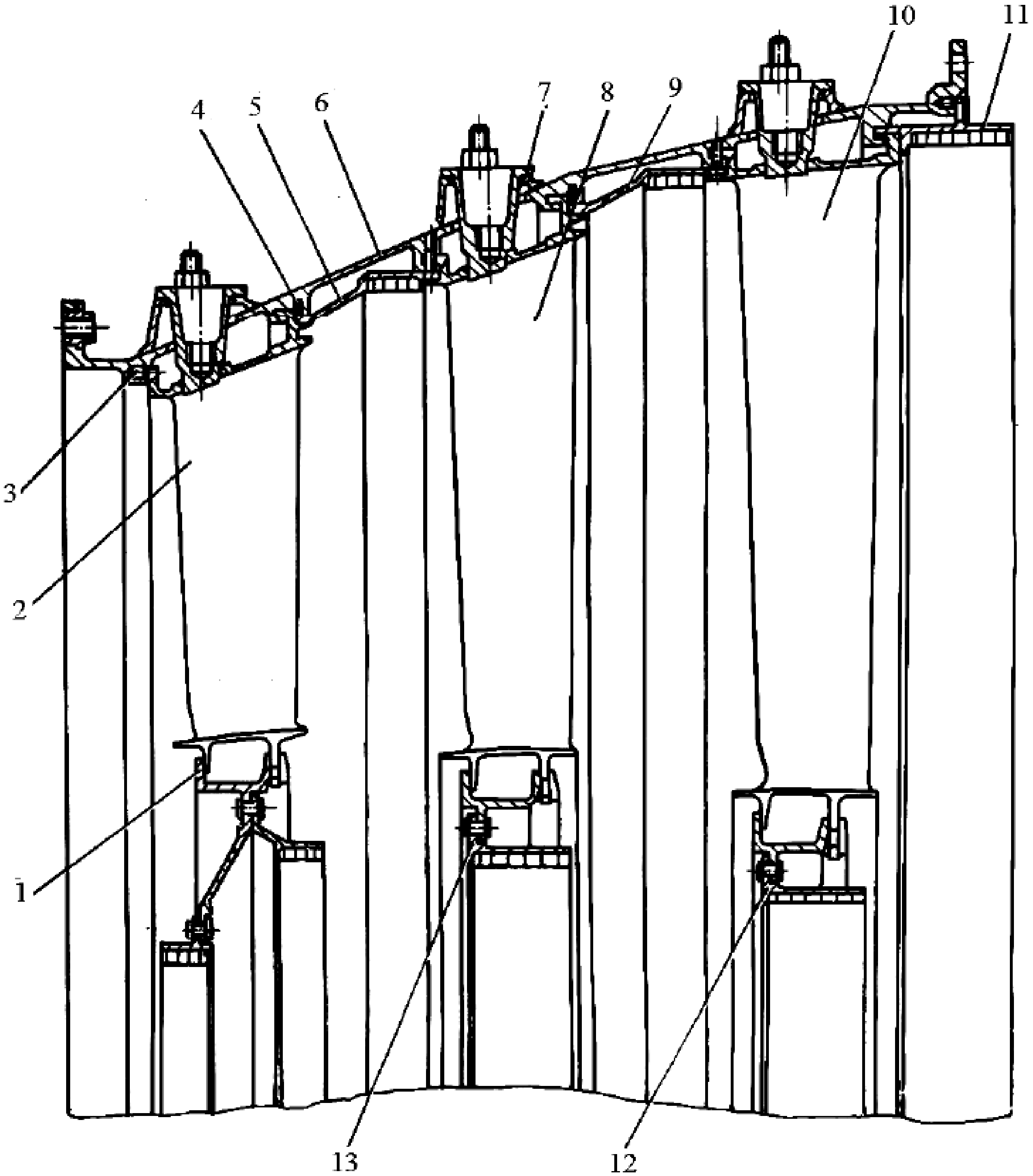


Figure 5.19 – Fan turbine stator:
1 – inner housing of the III stage nozzle; 2 – sector of the III stage nozzle vanes; 3 – pin; 4 – retaining ring; 5 – III stage spacer; 6 – outer case; 7 – plug; 8 – sector of the blades of the IV stage nozzle vanes; 9 – IV stage spacer; 10 – sector of the nozzle vanes of the V stage; 11 – V-stage spacer; 12 – inner case of the V stage nozzle vanes; 13 – inner case of the IV stage nozzle vanes

Figure 5.20 shows the design of the III stage nozzle vane sector, which consists of outer 3 and inner 5 shroud plates and four vanes 4 between them. The sector of nozzle vanes enters the corresponding grooves of the outer casing by ledges 1 and 2 located along the outer shroud plate.

The inner housings 1, 12, 13 (see Figure 5.19) consist of rings, the grooves of which are used to center the housings on the ledges of the inner shroud plates of the sectors of the nozzle vanes, diaphragms and O-rings with honeycomb elements of the labyrinth seal.

The fixation of the sector 2 of the III stage nozzle vanes in the circumferential direction is carried out by the pin 3 pressed into the groove of the outer housing 6; in the axial – by retaining ring 4.

On the shoulder of the inner shroud plate 5 of the sector (see Figure 5.20) there is a ledge 6 for fixing in the circumferential direction of the inner case.

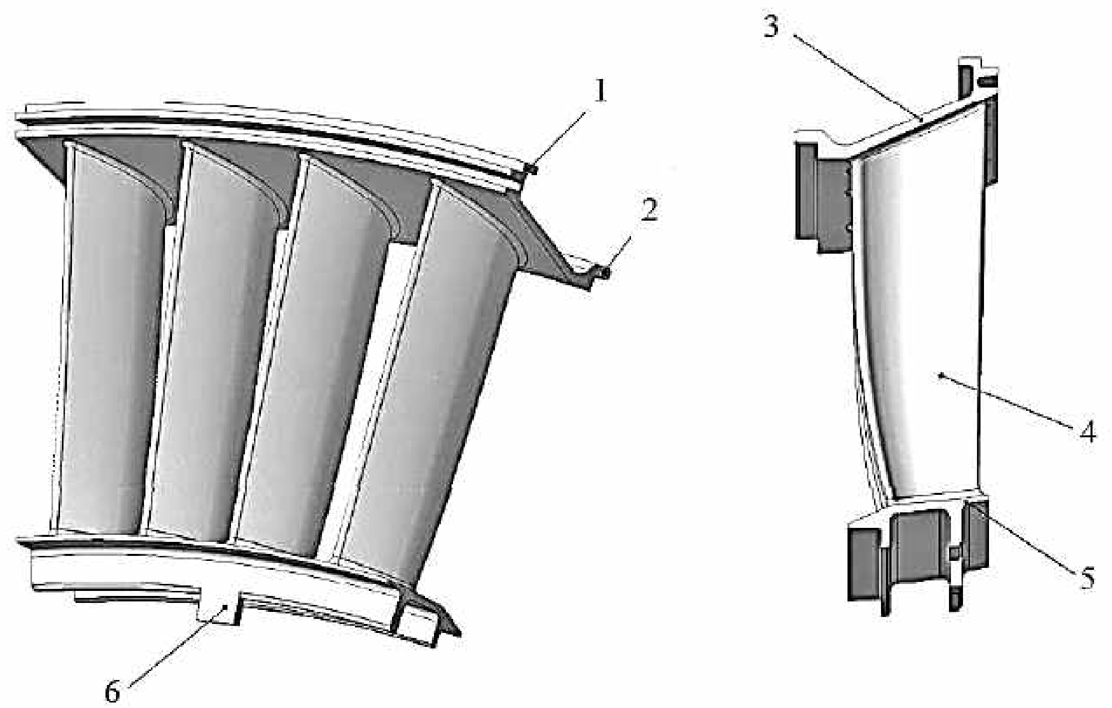


Figure 5.20 – Fan turbine nozzle vanes sector:
1,2,6 – ledges (spigots) on the shroud plates; 3 – outer shroud plate;
4 – nozzle vane; 5 – inner shroud plate

The design of the sectors of the fan turbine IV and V stages nozzle vanes is similar to that described above and differs only in geometric dimensions.

The rotor (Figures 5.21 and 5.22) of the fan turbine consists of a stage III impeller - 3, a IV stage impeller - 2, a V stage impeller - 15, a shaft 19 with a roller bearing 22, a nut 26, a washer 25, washer 25, locking it, a labyrinth ring 24, bolts 8, nuts 7 and washers 6, tie bolts 18, with nuts 17 and washers 16, O-rings 1, thrust rings 21, 23 and parts of an air-tightened seal.

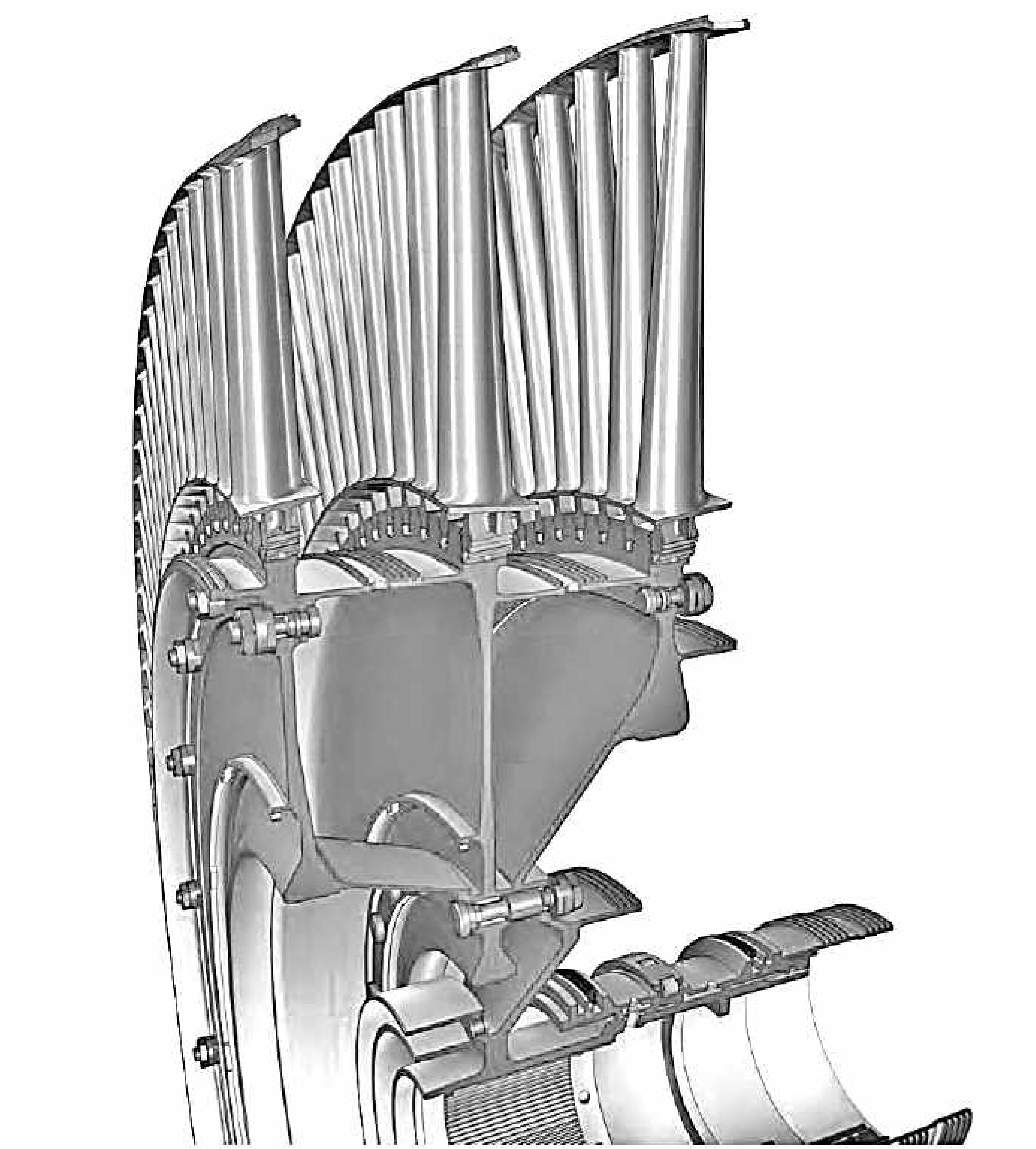

Figure 5.21 – Rotor of the fan turbine (section of the solid model)

Each impeller 3, 2, 15 (see Figure 5.22) consists of disks and rotor blades 10, 11, 13, fixed in the axial direction by plate locks 9, 12, 14. Impellers 3, 2 and 15 are connected to the shaft 19 by sixteen tie bolts 18, the conical fit sections of which are used for centering and transmission of torque. The nuts 17 of the tie bolts are secured against unscrewing with washers 16.

Impeller 2 of FT IV stage is connected to impellers 3 and 15 by sixteen bolts 8 at each joint. Nuts 7 are secured against unscrewing with washers 6.

The rotor of the fan turbine is balanced by placing weights 4 installed in the grooves under the collars of the FT rotor stages disks III, IV, V, which are fixed in the circumferential and axial directions with locks 5.

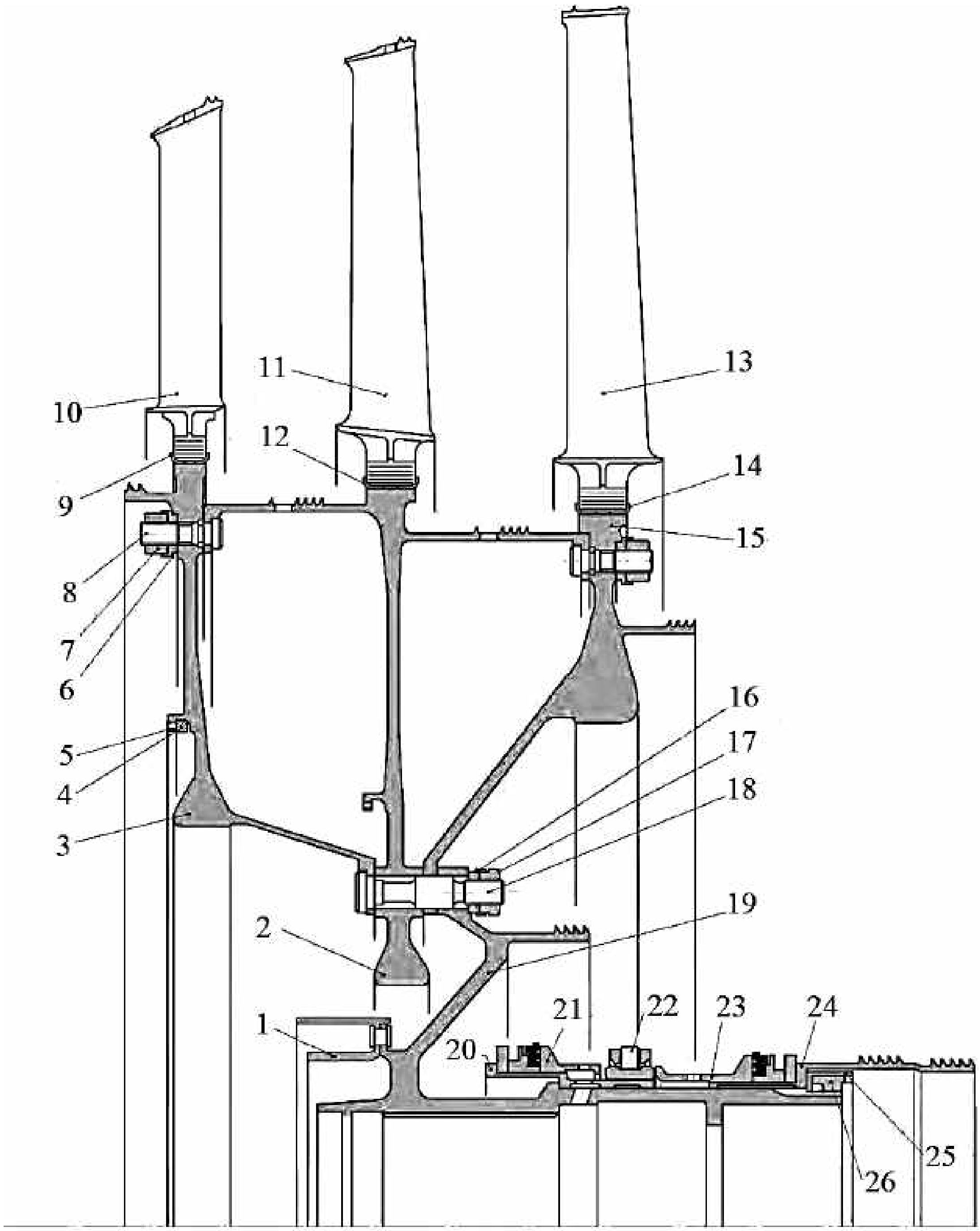


Figure 5.22 – Fan turbine rotor:
1 – a sealing ring; 2 – stage IV impeller; 3 – impeller of the III stage; 4 – balancing weight; 5 – lock; 6, 16, 25 – washers; 7, 17, 26 – nuts; 8 – bolt; 9,12,14 – plate locks; 10,11,13 – working blades; 15 – impeller of the V stage; 18 – coupling bolt; 19 – shaft; 20 – bushing; 21, 23–- thrust rings; 22 – roller bearing; 24 – labyrinth ring

### 5.5 Cooling System

Heat-stressed parts of the turbine (disks, HPT impeller blades, HPT and LPT nozzle vanes, supports housings) are cooled by air taken from LPC 17 stage, of the HPC 3 stage and from the HPC 7 (last) stage (Figure 5.23).

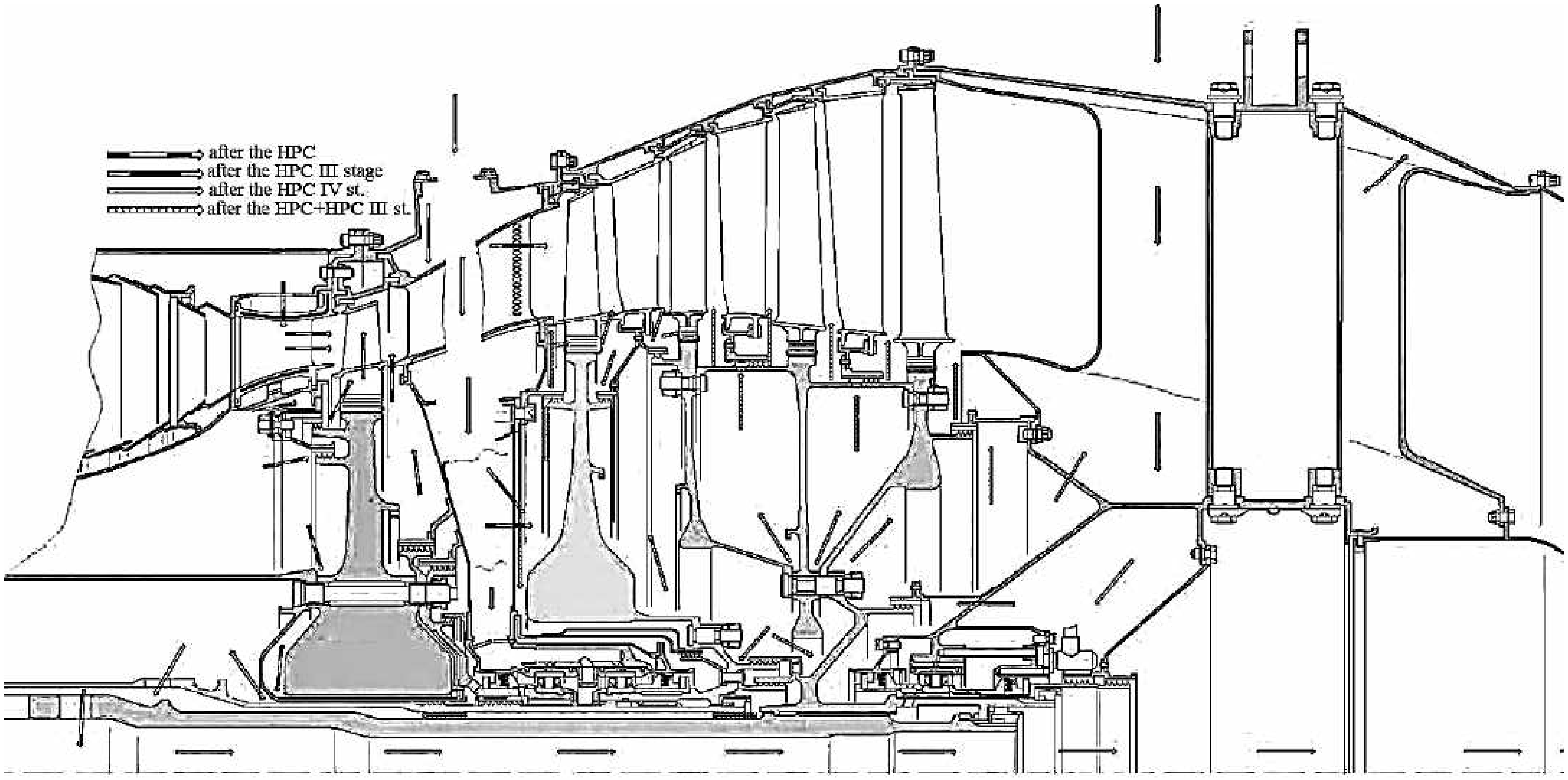


Figure 5.23 – The turbine cooling scheme

High-pressure turbine nozzle vanes are cooled by air from HPC, which enters from the outer end of the vane inside the deflector. Through the holes in the baffle air enters the clearance formed by the deflector and vane walls, and enters into the gas path through holes in the vane trailing edge.

The blades of the impeller of HPT and high-pressure turbine disk are cooled with air coming out of the 7 (final) stage of the HPC.

The low-pressure turbine nozzle vanes are cooled by a bleed air from HPC 3 similarly HPT nozzle vanes cooling. LPT and FT disks are cooled by the same air flowing into the cavity of the LPT nozzle unit inner housing and mixing with air, which washes the HPT disk.

To ensure the necessary operating temperature HPT and the LPT bearings are cooled by air from the LPC 4 stage through the internal cavities of the low-pressure turbine nozzle vane unit. Air prevents the flow of heat from the HPT and LPT disks and provides the necessary pressure difference in the labyrinth and tight seals. Fan turbine bearing is also cooled by this air.

## 6 BACK SUPPORT AND JET NOZZLE

The back support (Figures 6.1 and 6.2) is the turbine power unit which consists of an outer housing 2, the inner housing 32, the eight power struts 4 with fairings 10 and includes a front sealing ring 28, spray nozzles housing 24, the oil damper left 27 and right 25 rings, sealing rings 13, 20, 26, an oil supply pipe adapter 39, venting pipe adapter 38, oil scavenge (from the oil cavity) pipe adapter 40, the bleed air adapter 30, communications located inside the fairing 10, a rear cover 23, cap 16 and exhaust cone 18.

The back support (see Figure 6.1) by ninety bolts, ten of which are tight-fitting, is attached to the stator of the fan turbine and use for placement of the fan turbine roller and includes a ring of an engine mount for the aircraft.

In addition, the back support, cap and exhaust cone form a gas – air path (jet nozzle) at the outlet of the engine in which heat and pressure energy is converted into kinetic energy of the stream, creating engine thrust.

The outer casing 2 (see Figure 6.1) is of welded structure and consists of a front and rear flanges, of the front and rear cones, hang ring 7, communications mounting flanges.

Power struts 4 are of welded structure composed of two gaskets and spacers there between. Power struts are attached to the outer casing 2 and inner casing 32 via power - bolts 5, 8, locked from unscrewing with bushings 6, 9.

The inner housing 32 - welded structure which consists of a power ring 21, bearing housing 30, flanges and cones, fastening their, the rings 31, 33 of the labyrinth seal with cellular elements.

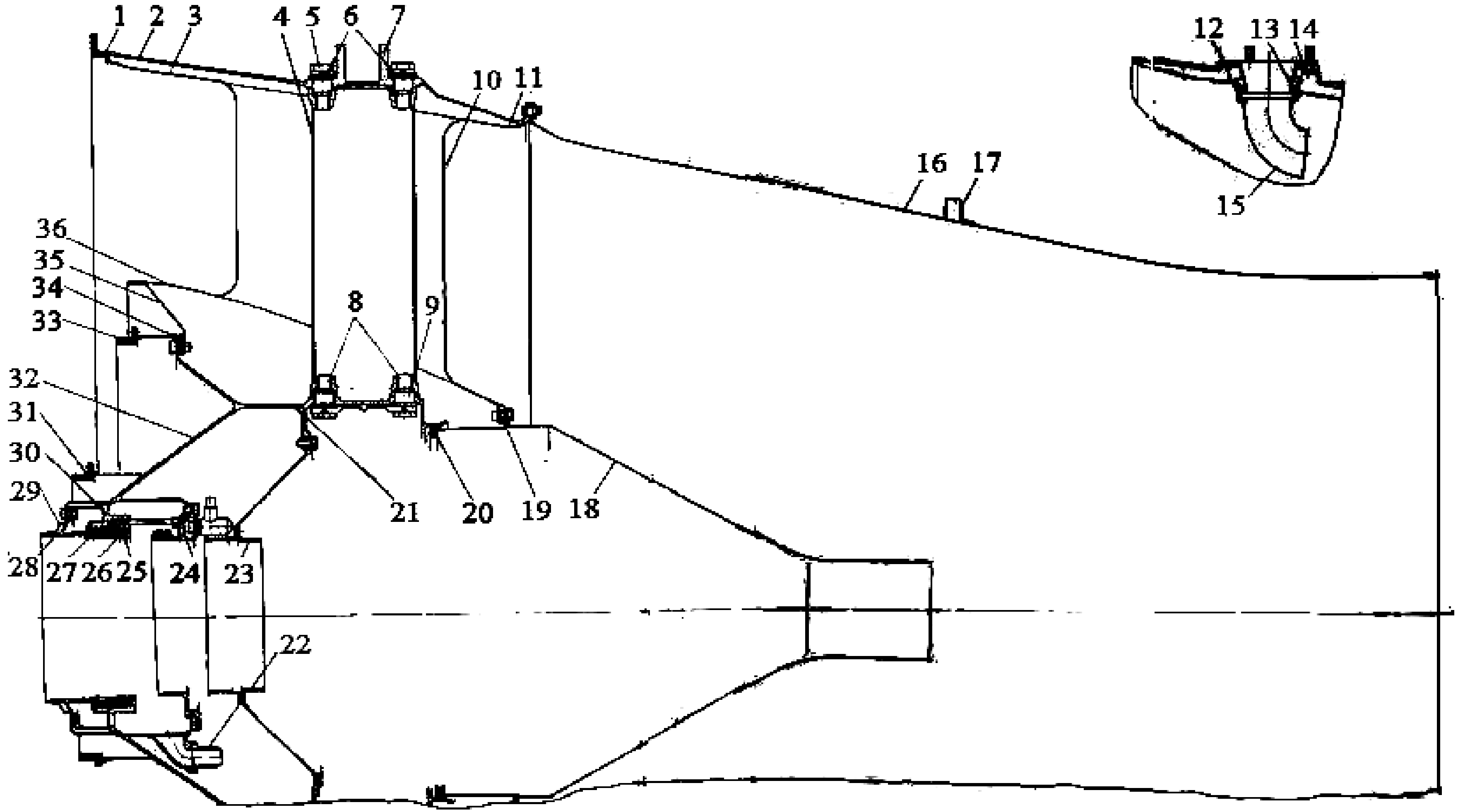


Figure 6.1 – Turbine rear support:
1 – front ring; 2 – an outer housing; 3 – the outer casing; 4 – power strut; 5, 8 – power bolts; 6, 9 – hubs; 7 – hung ring; 10 – cone; 11 – rear ring; 12 – flange; 13, 20, 26 – sealing rings; 14 – transition hub; 15 – a branch pipe; 16 – cap; 17 – stiffness ring; 18 – exhaust cone; 19, 34 – flanges; 21 – power ring; 22 – oil scavenge pipe adapter; 23 – a back cover; 24 – the case of the nozzles; 25 – ring (right); 27 – ring (left); 28 – a sealing ring; 29 – the screen; 30 – the bearing housing; 31, 33 – ring labyrinth seals with cellular elements; 32 – inner housing; 35 – cone; 36 – the inner casing

Turbine supports housing is of welded structure, consists of the front 1 and rear 11 rings, the outer casing 3, eight fairings 10 and the inner casing 36, flanges 19 and 34. Inside the cowls 10 of casing 3 the pipes are located. They are used for oil supply to the fan turbine bearing and to an oil damper, for oil pumping out, venting, air bleed. To the outer casing 2 by means of seventy-two bolts cap 16 is fastened, and to the flange 19 - exhaust cone 18, using sixteen bolts.

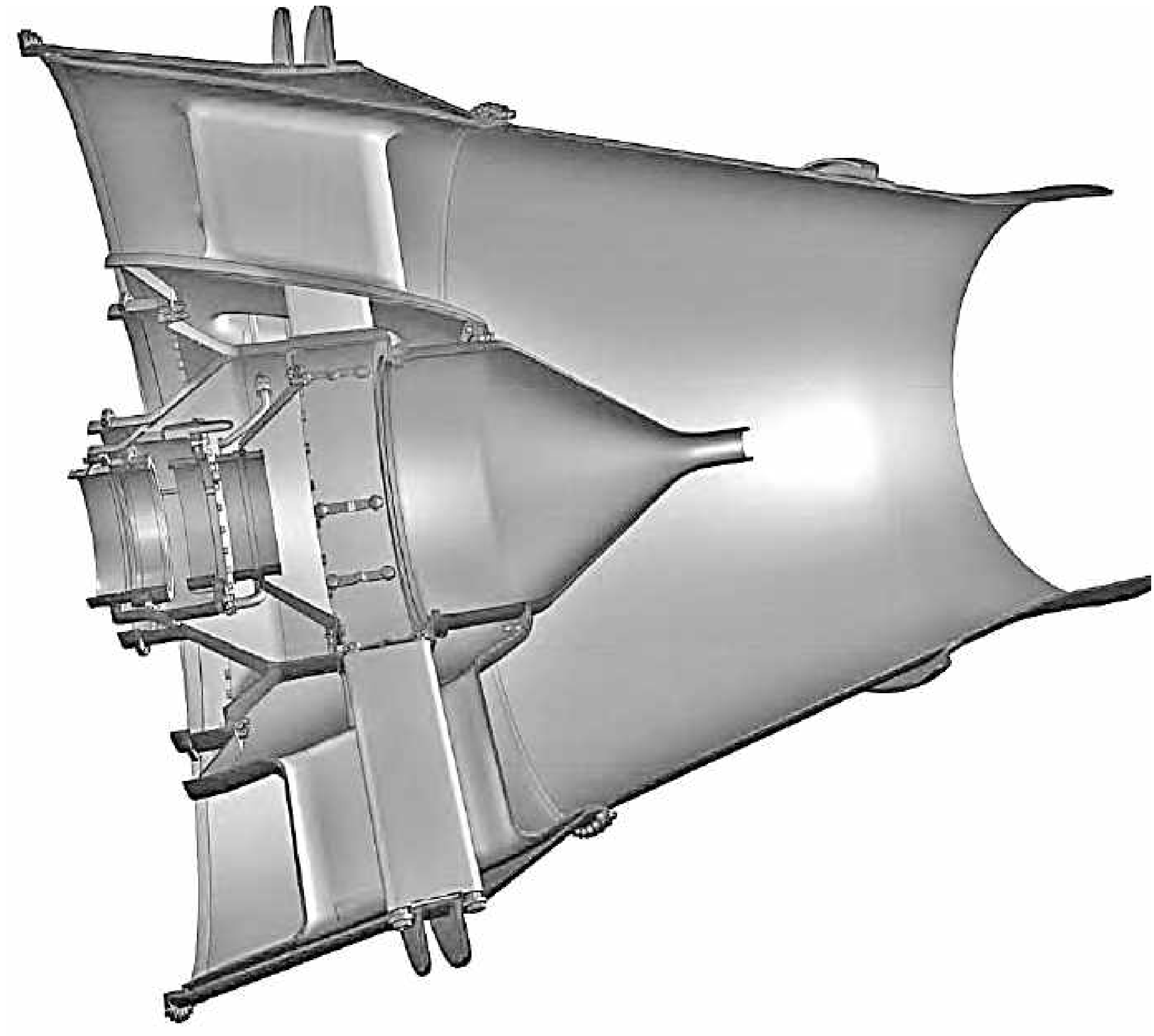

Figure 6.2 – Turbine rear support (solid model section)

# 7 LUBRICATION SYSTEM

Lubrication system of engine D-36 is circulating and autonomous, i. e. all the units of lubrication system are mounted on the engine.

While normal operating mode the oil temperature on the outlet should be not higher than 130 °C and on the inlet about 60…80 °C to keep the temperature of bearings in the specified limits. The optimal oil temperature differential $t_{out} - t_{in}$ is desirable about 20...40°C. Heat emission to the oil on D-36 is 650…2550 kJ/min if the oil circulating is 18 l/min. Used oil is ИПМ-10 or ВНИИ НП-50-I-4Ф.

Oil losses on D-36 are not too much. Losses are caused by oil leakages through the labyrinth seal and air breather to the atmosphere and their value is not higher than 0.8 l/h.

Lubrication system diagram of D-36 is on the Figure 7.1.

## 7.1 Operation of Lubrication System

Oil from the oil tank 5 is supplied by gravity to the supply section 30 of oil unit. Oil from supply section is supplied to the fine filter 28 (that located in the oil unit case) under the pressure. Oil pressure at the inlet of the engine is kept by the reducing valve 23.

When oil leaves the oil unit it is supplied to the side rib of the intermediate case through the external pipeline. Then oil passes through rib cavity and divides into three flows. One flow lubricates and cools bearing of the HPC rotor and center drive. The other one lubricates and cools bearings of the LPC and fan. The third lubricates and cools bearings of all turbines.

Oil is supplied to the rotor bearings through the oil spray nozzles. The safety filters are installed before the oil sprayers. The other units are lubricated with splash lubrication.

The oil from cavities of fan bearings, LPC bearings and turbine bearings is pumped out by sections 22. The oil from HPC rotor bearing cavities flows by gravity to the accessory gearbox lubricating and cooling parts of center drive and accessory gearbox on the way.

The oil from all cavities flows to oil chamber of accessory gearbox. All the oil from oil chamber of accessory gearbox passing shaving indicator 17 is pumped out by main pump out section 22. Then it flows to centrifugal deaerator 10 through the channel in the accessory gearbox. The separated from the air oil flows to the fuel-oil unit 9 for cooling. Then it flows to the oil tank 5.

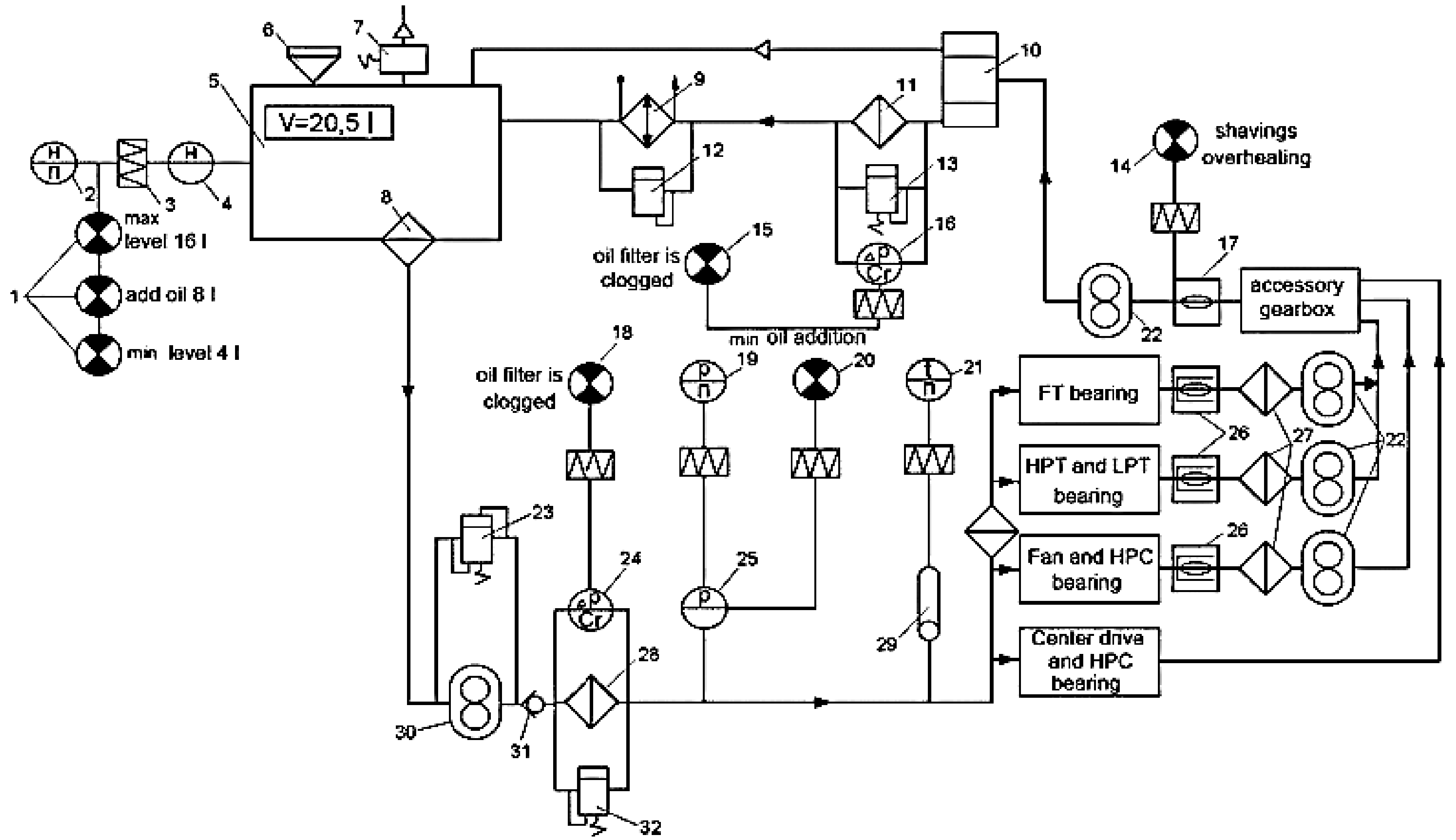


Figure 7.1 – Lubrication system diagram of TFE D-36

Legend in Figure 7.1:

1 – indicator of oil meter; 2 – oil meter; 3 – electric signal transducer; 4 – oil level sensor; 5 – oil tank; 6 – filler with the filter; 7 – safety valve; 8 – safety oil filter; 9 – oil fuel unit; 10 – centrifugal deaerator; 11 – rough filter; 12 – thermal valve; 13 – bypass valve; 14 – overheating and shaving presence indicator; 15 – rough filter clogging indicator; 16 – differential pressure sensor; 17 – magnetic indicator of shavings; 18 – fine filter clogging indicator; 19 – oil pressure pointer; 20 – minimal oil level indicator; 21 – oil temperature indicator; 22 – scavenge section of oil unit; 23 – reducing valve; 24 – differential pressure on fine filter indicator; 25 – pressure sensor; 26 – thermal and shavings indicators; 27 – safety filters of pumps; 28 – fine filter; 29 – oil temperature sensor; 30 – supply section of oil unit; 31 – check valve; 32 – reducing valve.

Oil pressure at the engine inlet is measured by sensor and indicator 25. Minimal pressure is checked with indicator 20. Oil pressure at the engine inlet is kept in the range:

- 3.5 ± 0.5 kg/sm$^2$ – on the ground with rotor rotational speed $n_{HP}$ = 95% and inlet oil temperature 70 ± 15 °C;
- 2.0...4.5 kg/sm$^2$ – on all other operational modes and conditions.

Oil temperature at the engine inlet is monitored by sensor 29 and indicator 21 data. The thermal shaving indicators 26 are installed in the pumping out pipeline. They give signals when ferromagnetic particles appear in the oil or when the oil temperature exceeds 207°C.

The ferromagnetic particles appearance in the oil from accessory gearbox is indicated by shavings indicator 17.

There is a display of lubricating system parameters on the pilot desk in the cockpit:

– display «Minimal oil pressure» lights up when the oil pressure at the engine inlet has minimal value;

– display «Shavings» lights up in case of ferromagnetic particles presence or in case if the temperature exceeds the specified limits;

– display «Oil filter is clogged» lights up when the value of the differential pressure on fine filter reached specified value;

– display «Minimal oil level» lights up when the oil level in the oil tank is lower than specified minimal level.

The centralize oil filling panel is in the tail of fuselage from the right. There is an indicator of oil level in the tank, display “Minimal oil level”, display “Add oil”, display “Maximal oil level” on that panel.

There are discharge cocks at the bottom of the accessory gearbox, on the oil tank and on the fuel-oil unit. They need to discharge oil from engine.

Total maximum oil level in the lubricating system is 27 liters. 16 liters – are in the tank, 2 liters – in the fuel-oil unit the rest – in the oil cavities, pipelines and lubricated units. Display «Add oil» is lighted up when the oil level in the tank is 8 liters. Display «Minimal oil level» is lighted up when the oil level in the tank is 4 liters.

The oil cavities of engine are isolated from air and gas cavities with the seals. The oil cavities are connected with the atmosphere to provide normal operation of lubricating system and its seals.

On D-36 the oil cavities of turbines, of fan and LPC bearings are breathed through the expansion box and centrifugal air breather.

The oil cavity of HPC bearing is connected with the centrifugal breather through the accessory gearbox cavities.

Centrifugal breather CB-36 is located in the rear right part of accessory gearbox. It fastened with help of hanger bolts and prevents oil losses while breathing oil cavities of the engine.

### 7.2 Lubrication System Maintenance

Most faults of lubricating system happen because of faults of lubricating system units, heightened wear of lubricated parts and violation of maintenance rules of lubricating system and engine.

Oil penalty, decrease of oil supply to the lubricated units, oil contamination and oil overheating give evidence of lubricating system faults.

Oil penalty happens in case of oil pipelines and cavities decapsulation, for example in case of pipelines and their connections destruction, in case of wear of rotor bearing seals, in case of crack in cases of accessory gearbox or lubricating system units and so on.

Large oil losses may be connected with its emission through the breathing system in case of destruction of the deaerator or breather drives. Large oil consumption is inadmissible because the oil reserve may end, oil supply to the engine may stop and rotor bearings will be destroyed.

Decreasing of oil supply to the engine results in deterioration of cooling and lubricating conditions of lubricated units. This process is called “oil starvation”. Oil starvation results in intensive wear, overheating and may lead to rotor jamming. Oil starvation happens in case of oil pressure drop after the oil supply section and hydraulic resistance increasing in the oil supply pipeline. It may happen for example in case of fine filter clogging or carburization of oil sprayers.

Reasons of pressure drop in the oil supply pipeline may be large oil losses, heightened wear of parts in the pump supply section, spring of the reducing valve weakening or sticking in open position (because of clogging with mechanical particles).

Oil contamination results in fine filter clogging. Filter clogging results in open of bypass valve. As a result raw oil gets to the engine. The wear debris, carbon and other impurities result in heightened wear of friction units and bearing seals, decrease of cross-section of oil sprayers, jamming of pumping units, destruction of drives, clogging of fuel-oil unit and so on.

Oil overheating happens because of extra heat generation in case of intensive wear of friction units, in case of oil starvation, in case of excessive rotational speed of rotors, excessive gas temperature and so on. Excessive of permissible temperatures result in oil oxidation, emission of carbon and tar which clog filters and sprayers, deterioration of lubricating and anticorrosion properties of oil.

Pollution and overheating of the oil change color of the oil to more dark. It is a sign of overheating and destruction of lubricated parts. It primarily concerns the rotor bearings.

The reasons of rotor bearings damage are:

– fatigue failure of material in the contact area of rolling bodies and race track;

– heightened slipping and wear of bearing parts;

– bearing operation in condition of oil starvation.

Fatigue failure of bearings is a material micropitting of rolling bodies and race tracks. Micropitting may be a result of high centrifugal forces from rolling bodies, material hardness decreasing after short-term overheating, and corrosion because of bad conservation.

Wrong installation of bearings (large clearance, bearing rings misalignment) results in heightened slipping and wear. As a result of wear the wear products can get to the contact area of rolling bodies and provoke jamming of bearing.

Wear and thermal deformation provide clearance changing that is influent to the bearing operability. For example, if the engine shut down without cooling on low operational mode the heat flow from turbine disk may result in an expansion of internal ring of bearing, reducing clearance and short-term jamming. After total cooling-down of engine the clearances are restored but high contact stresses after jamming may result in a deformation of contact surface and their cracking.

When cold engine is started up the viscosity of oil is high and oil supply to the bearings is complicated. Rolling bodies without enough lubrication may heat, reduce the clearance with the rings and jam or destroy the bearing.

The melting and wear of rolling bodies, galling of balls material to the race tracks, wear of outer surface of separators and its housings, rupture of side separator connections are always take place as a result of oil starvation.

Lubricating system maintenance is a part of the whole preparation process of the aircraft to the flight and it is carried out in time of operational activities and scheduled maintenance.

The main activities of lubricating system maintenance are check of units and pipelines condition, oil level control, oil discharge and oil filling. Inspection of lubricating system is provided in time of maintenance. The absence of oil leakages, pipeline, fasten and bonding damages are checked during inspection. The oil level and filters are inspected every 50 hours of engine work.

Every 200 hours of engine work the oil should be changed oil level indicator should be checked and washed.

The oil level and oil temperature should be checked before engine start-up. Minimal allowable outside temperature of engine start-up is –40°C. If outside temperature is lower than –40°C the engine should be heated from heat machine. If the oil temperature is lower than –20°C the heating process is carried out 30…40 min until oil temperature is +5°C.

In time of engine testing the oil pressure and oil temperature are controlled and operating of signaling indicators is checked.

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