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ST.PETERSBURG, RUSSIA

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Main gearbox is a part of powerplant which determines helicopter flight tasks to marked degree. The experience of "Klimov" Corporation in main gearbox strenght for medium - to - heavy size helicopters with load - lifting capacity of 7 - 14 tons is described.

It is shown that all the efforts for main gearbox strenght provision are subordinated to start-to-finish single program providing system approach to construction creation.

MGB configuration development at the early design stage is provided by multivariant theoretical analysis of stresses and deformations appearing in parts with gearbox loading in flight operational cycle. In parallel with this the results of the theoretical recommendations are concurrently realized in design decisions.

Special importance is given to the experimental verification of the models embodied in the construction for the construction certification requirements and to the main gearbox reliability and service life. These goals are achieved by conducting mechanical tests of the separate parts, units and full-sized gearbox.

Description of major tests, technique of bench tests and flight tests is given.

Klimov Corporation was at the beginning of the Soviet helicopter building when 35 years ago it created the power plant of two GTD-350 turbine engines and main VR-2 reduction gearbox for Mi-2 helicopter.Then the Corporation kept the role of the leader in the development of full component power plants of all kind of arrangements, comprising engine - driven shaft - main reduction gear box for helicopters of (7 - 14)t takeoff weight. Total productionmain geaboxes (MGB) to 30.000 including ones for unique production helicopters of coaxial system with two coaxial rotors. Some characteristics of main gearboxes bein in operation are given in table 1.

Table 1

Helicopter	Mi-2	Mi-8	Mi-14	Mi-24	Ka-32	Ka-50
Engine	GTD-350	TV2-117	TV3-117	TV3-117	TV3-117KM	TV3-117VMA
MGB	VR-2B	VR-8A	VR-14	VR-24	VR-252	VR-80 PVR-800
Two engine take-off power, HP	874	3000	4200	4400	4400	4400
MGB maximum confingency power(one side input)HP	437	1500.	2425	2425	2425	2400
Main rotor shaft speed, r/min	246	192	192	240	272	313
MGB input speed,r/min	5804	12000	15000	15000	15000	15000
Total transmission ratio of the MGB	0.0417	0.016	0.0128	0.016	0.01815	0.02086
Maximum take-off weight of helicopter,kg	3700	12000	13600	13000	11700	9800
Overload factor at the center of gravity,g		3	3	3	2.5	2.5
Tale rotor speed,r/min	2460	2589	2593	3237	-	-
Time between overhauls (TBO) of MGB, hour	1000	1500	1000	1000	500	300
Total life of MGB,hour	4000	12000	3000	3000	1500	900
Seiling,m	3500	5000	5000	5000	5000	5500
Ambient temperature, C	+50	+60	+60	+60	+60	+60
The dry mass of MGB,kg	300	785	842.2	830	1025	925(1063)

Main reduction gearboxes parameter levels were in full accordance with the technical task requirements by the time of delivery.
Each reduction gearbox design system (special features) depends on originality of power plant arrangement on helicopter. Power plants are of different types as it can be seen in fig.1.
Main reduction gearbox construction conforms to the arrangement special features of single-rotor or two-rotors helicopter.It means that the construction provides the opportunity of relative location of the engines and the main reduction gearbox with front, side or rear engine location; at all arrangements it provides load transmission from the rotor (of system) to the helicopter

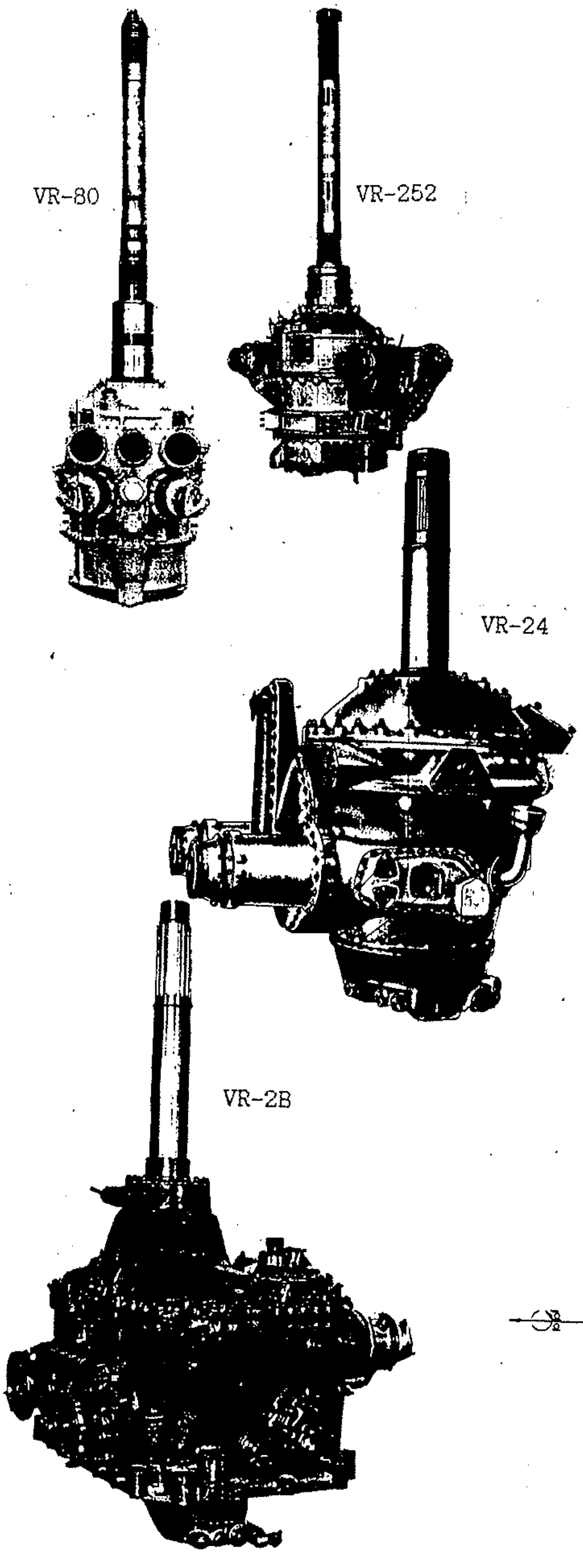

Fig.1

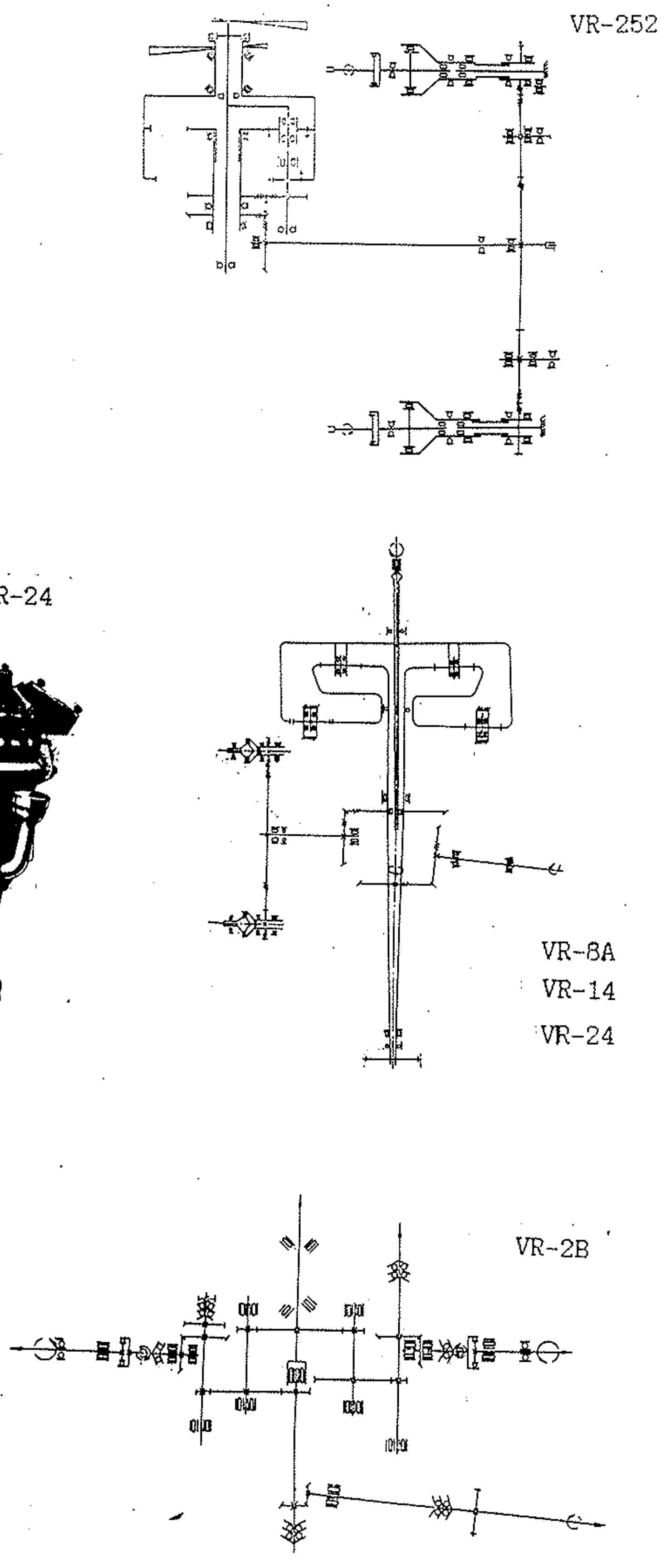

Fig.2

fuselage and also force support of the rotor control system. In spite of the variety of arrangements of reduction gear models system an obvious design continuity is preserved: summing of two engines pover; use of planetary gear trains; use of overrunning clutches at each inlet to the reduction gearbox; production of cases out of magnesium alloy; high coefficient of serrations engagement including planetary orders; altitude, angle and profile correction of serrations; introduction of damping into gear units; use of tapered roller bearings with moderate rotation speed; use of double slag remelting materials for gears and shaft; use of materials with high tempering temperature for bearing rings if it is necessary; pressure lubrication of all engagements and bearings; high quality cooling of oil; multiparameter diagnostics system; a large number of mutual unification elements and standard elements.
Presented list is not full, but it is sufficient.Though the gearbox is standardized and unified some patents are received.It is known, that positive previous experience used in construction contributes to parameters stability and reliability of new construction being designed.
The basic problem of aviation conception - safety - is provided by this.The provision of strength is an essential part of conception.
This statement is extending on MGB of all applications.For its realisation Klimov Corporation has launched research and development programs, of forecast and provision of static and dynamic MGB behaviour.These programs form a block of computerized design system.The methods of analytic research and strength tests are well mastered, they are used from the first stages of design.
As a result a number of cycles model-tests reduced and as well as a considerable part of production cost.
The visible side of strength deficiency is the components integrity fault or deformation.The last one is a consequence of change of inequality sign in the relation:

$$R < N \, , \qquad [1]$$

where R - acting generalized load factor
H - component generalized ability to resist type of load being considered.

The origin of R in the units of helicopter power plant is an aircraft mission being performed and also the functional interaction of the power plant units and components in operation.
The H value in its turn sums up the kowledge of material properties and the components configuration effect upon load carrying capability.
The H and R values are properly calculated statistically.In order to ensure some unfailure probability, the inequality [1] shall be reinforced by introducing ratio K > 1 into the left part:

$$\frac{H}{R} > K \qquad K > 1$$

The choice of "K" - (ratio of margin) value is a separate task, it is in compliance with the structure components of each type and is related to the unfailure probability by the following equation:

$$\gamma = \frac{k-1}{\sqrt{\vartheta^2 k^2 + \vartheta_R^2}}$$

where - Gaussian measure of reliability related to reliability of unfailure P by the following equation:

$$p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\gamma} \exp\left(-\frac{\vartheta^2}{2}\right) d\vartheta$$

or in a tabulated form:

P	0.9	0.99	0.999	0.9999	0.99999	0.999999
	1.28	2.33	3.09	3.72	4.26	4.75

$\vartheta_H = \frac{S_H}{\bar{H}}$ - load-carrying capacity variation ratio

$\vartheta_R = \frac{S_R}{\bar{R}}$ - load variation ratio

K - conventional ratio of margin

$$k = \frac{\bar{H}}{\bar{R}}$$

According to the standards the maximum load and minimum load-carrying capacity enter the analysis.In this case the strength margin is formed taking into account the confidence probability, the Rmax and Hmin values of load and load-carrying capability, respectively, being taken with.
So, strength is being provided by:
- the knowledge and the studies of the loads;
- the knowledge of how the construction reacts to these loads;
- the use of high-quality materials;
- constructive ensurance and maintenance of the designed components interaction during the service life;
- the maintenance of production quality;
- the integrity substantiation by the service life tests;
- the complex of measures during the operation.

To solve the above listed items "Klimov" has the corresponding equipment, enrolls the high qualified specialists,test facilities. The following MGB types are being operated now (see Table 1). All of them were designed for the power plants of the helicopters equipped with engines also designed by "Klimov". The Figures 1 and 2 presented the MGB external view and functional diagrams. These designs are rather complicated. A Fopple, German specialist in the field of integrity, said "any structure is intended for the transfer of forces in space ". From this point of view, the helicopter MGB is a typical example of load-carrying structure.
First, MGB is a power transmitting link from power plant, incorporating the engine, transmission and the propeller shaft, to the rotor. In the structures designed by "Klimov" the propeller shaft is a MGB configuration assembly. That is why the MGB also works as a load-carrying structure of helicopter fuselage and furthermore as a structural basis for rotor control system.
In other words, MGB as a load-carrying structure concentrates three loading systems, defined as:
1st - by the complex of engine ratings in compliance with the flight cycle and cyclogram of accessories loading;
2nd - by the loads, caused by the helicopter mission;
3rd - by the complex of loads in the rotor control system.

In connection with the above said the MGB strength requirements are defined by various standards:
- helicopters strength requirements
- main gearboxes strength requirements
- engine strength requirements
- accessories strength requirements.

These standards regulate the minimum strength requirements for the structure and are included into the requirements NLGV (Common airworthiness requirements).
In compliance with these standards the MGB components shall resist numerous mechanisms of failure - static deformation, low-cycle and high-cycle fatigue against the environmental background such as wear, corrosion, heat, re-

ducing the failure strength of the structure.
Moreover the load-carrying structure shall hold its geometry under the operation load withing rather close tolerance limits in order to ensure the operability of such transmission units as bearings and engagements. MGB casing shall resist the loads during incidents.
So, MGBs have a number of structural features, allowing to separate them into an independent structural type group of mechanisms.The development of the MGBs goes in the direction of the intensification of those features which distinguish them from the other structures of close related types.
Peculiar method of approach is also required for MGB strength.
The means to ensure the MGB strength according to (1),(2),are being divided in several areas:
- affecting the structure of stressed-strained state through geometry;
- affecting the properties of the component material;
- affecting the field of forces through the choice of rational structure diagram and operating regimes.

The methods, providing the work in these areas, are divided into two parts:
- analytic methods, which are subdivided into calculated (analysis) and designed (synthesis) methods;
- experimental methods, subdivided into research and qualificational methods.

The program of strength provision is being created on specifications and its correspondence to the requirements to state regulating documents.
Fig.3 shows block-diaghram of quality assurance system during power unit development and design, which includes "Klimov Corporation".
As seen from the block-diagram, the quality of design - result of development - is determined by:
- the system must comprise all the stages of the process from technical requirement till launching of the production sample into operation;
- the principle of feedback loop use, in which the uncorrespondence between technical requirements and design is determined by X,Y,Z,
  where: X - independent organizations of customers;
  Y - independent organizations of manufacturers;
  Z - independent organizations of operators,
- arrangement of internal control feedback loops of finished stages approval by the main specialists and coordination of every assembly by allied departments and technological services. Operations of approval and accordance serves as a feedback loops closure mechanism.
- by accumulation of customer and independent experts experience obtained in specific developments in the process of work on parallel designs;
- fulfilment of requirements of state and branch standards, formulated taken into account Russia industry experience, that of other countries, including Klimov experience to a great extent.

In procedure of parametric strength design used by our company the strength properties are being considered as an product output parameter.

There the main units, components and the most typical parameters, that effect the strength are specified.
There the stage of revealing of those units and components which, by experience of earlier structures design, may be a potential cause of strength defects, is not shown. It does not mean the minor importance of this stage.
Actually, this analysis defines the outline of further frame work on integrity.
Work corresponding to the stages of design to the type schedule of MGB design.
The methods of strength parameters analytical estimation are in correspondence with the stages of MGB design: laying the foundation of the preliminary design, production design, development. "Know-how" gained by our company enables to avoid rather expensive changes at the end of the development stage in case when strength is not sufficient, e.g. at the expence of setting the differentiated strength margin at each stage of design. As the final stage of design is approaching the interaction between various components of working processes and conditions is being considered to a greater extent.

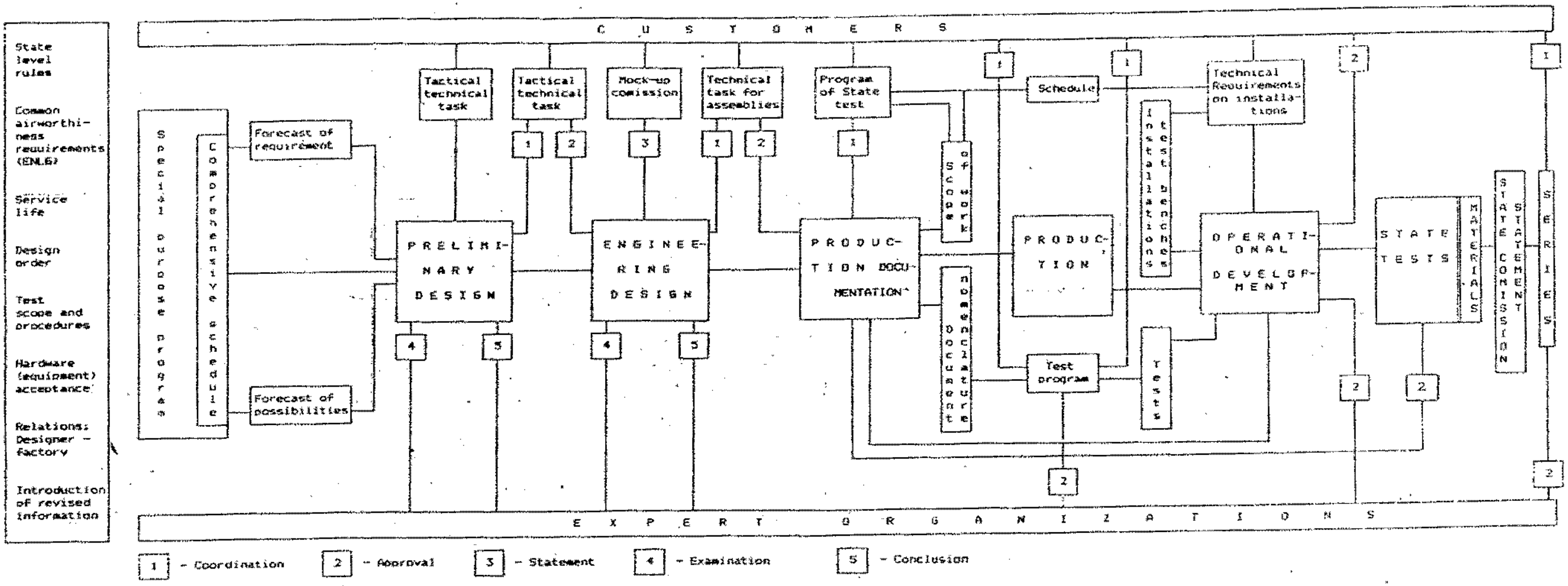
State level rules
Common airworthiness requirements (ENLG)
Service life
Design order
Test scope and procedures
Hardware (equipment) acceptance
Relations: Designer - factory
Introduction of revised information
CUSTOMERS
Special purpose program
Comprehensive schedule
Forecast of requirement
Forecast of possibilities
Tactical technical task
Tactical technical task
Mock-up comission
Technical task for assemblies
Program of State test
Schedule
Technical Requirements on installations
Installations test benches
Scope of work
PRELIMINARY DESIGN
ENGINEERING DESIGN
PRODUCTION DOCUMENTATION
PRODUCTION
OPERATIONAL DEVELOPMENT
STATE TESTS
MATERIALS
STATE COMISSION
STATEMENT
SERIES
Document nomenclature
Test program
Tests
EXPERT ORGANIZATIONS
1 - Coordination
2 - Approval
3 - Statement
4 - Examination
5 - Conclusion

Fig.3

The second group of analytical methods includes the design methods of synthesis and is based on the conceptions of Parametric Activity Function PAF and Parametric Image Function PIF, as statistic models suitable by minimum and allowable values of design parameters. The second group also includes making a design decision to realize these PAF and PIF.
At this point the decisions are selected which are tolerant to a dispersion of by-component and by-unit properties of the units placed on the lowest horizontals of the decisions hierarchy. Based on it, the MGB output parameters are being formed.
Let us follow how the direction of strength study is changing at each stage of the development.
The efforts for MGB strength begin with the edit and agreed of Technical Task supplementary sections (analysis and reciprocal proposals on loads, ratings, flight cycle of limit loads, offered by helicopter designers).
Values of inner load-carrying factors are revealed on the preliminary design stage. Their integration with inner loads information from Technical Task serves as a base for the total load-carrying decision of the main gearbox casings and their attachment to helicopter and engine.
Simultaneously mechanical diagram is being optimized and the main gearbox is arranged to the power plant. At the same time arrangement feasibility of kinematic diagram is being analysed within the limits imposed on engagement characteristics and achievement of units and parts predictable parameters composing the kinematic diagram correlated with clearance limits. The advantage that units elements of engagement transmission may be standardized and typically described designed in accordance with design rules (manuales, GOST [all union state standards], OST[branch standards], standards, reference books) is widely ised.
Development of main gearbox casing configuration as a fuselage element is being conducted to specific kinematic diagram and fuselage connection diagram. In this case there is no standard provision.
Detail design stage is characterised by predictable optimization and finally approved dimentions, which provide, in accordance with the drawing, required strength of a part limited by assigned service life and by flight cycles loading conditions. Gearbox integrity is being checked after its manufacturing.
During operation stage calculation and experimental works are being performed to analyse damages and failures in order to adopt special care and to facilitate test program including accelerated mission endurance test and actual service life expeditures.Simultaneously an allowable level of operation wear, developed plays and losses of kinematic precision are revised. The problem of service life maintenance and life extention as well as maintenance check, inspections and schedules are corrected.
In this case calculation technique is a base of analysis and one of the components of the structure synthesis semiback method. It means that the aim of calculation is not a figure itself, but insight into control of stressed--strained state and vibration processes both in parts and in the machine itself.
The following criteria define the choice of calculation technique: credibility (all union state standards, standards and guide lines); minimum of qualification expenditure; equivalence to the problem. As a rule use of a new instrument proves its value in case of new functional problem that can't be solved by proved methods.
While calculating transmission elements stressed-strained state methods based on various types of schematizing which means discrete models including elements from rods to space elements. Those methods have corresponding calculated forms up to finite elements method. Software used is primarily developed by Corporation.
Calculated schematizing is more individual at determination of casing elements stressed-strained state.
Effect of mechanical system dynamic properties on stressed-strained state is evaluated by spectral characteristics.
The following three types of vibration are taken into account:
- gear rotational vibrations caused by torque irregularity translated from driving forces and resistance forces as well as by peripheral components of

equivalent disc mass motion;
- bending vibrations, connected with rotational parts difficient balance and decenter of gravity caused by design, technology, production and operational causes;
- vibrations of gear wheel disc space shape, caused by dynamic loads occuring in engagement.

On design stage withdrawal of natural frequency spectrum components from operational speed area is a general practice for all gearbox models as well as provision of stressed level at estimated level of force effect with sufficient safety margin.

In practice the use of programs and methods in the form of reccurent procedures was quite warranted. They were adapted to determine natural frequency and shapes spectrum based on discrete schematizing for core systems and with use of plate and shell theories for gear disc.

Programs have a developed service, provide dimension data input by the drawing and automatical preparation of data on stiffness practically for all occured structures such as beams, casings, plates, etc.

Used design methods and technique allow to examine a large number of dimension and diagram versions of gearbox units and systems by computer. The examination begins with requirement development and finishes with evaluation of operation in various environmental conditions. In this case it is important not to shorten the term of design but to improve the design quality at the expense of omission of non-optimal versions. It means that errors number while designing will be reduced and the MGB quality and reliability will increase.

Number of versions on calculation stage forms a base for design period of analytical methods. In fact design period targets are connected with safety conception of MGB failure. In this case the choice of any technical decision coordinates with the factors which result in strength failure of a part at operation.

Requirements having a stimulating influence on reliability are included in technical documentation.

Having received approved results on design study of stressed-strained state a true non-coordination of stress level for a given type of damage mechanism and active loads in actual operation conditions is supposed to be a prerequisite for damage.

In process of design synthesis mismatch the possible causes are being studied, including:
- load growth as a cause of failure to satisfy a PAF during design process, that reduces loads from design area at the expense of more wide tolerance on PIF (contact spot, mounting clearance,etc)
- PAF deformation caused by malfunction of subsystem entering a PAF and appearing during operating life (loss of bearing tightening, disturbance of lubrication, displacement of bearing rings and loose fit etc) as a result of which the type of damage mechanism would change (it becomes off-design)
- technological violations that have an effect on:
  a) distribution of stress (that means on stressed-strained state) (cuts, chamfers, nicks, residual stresses)
  b) mechanical properties of parts

Overcoming of negative results of disturbances mentioned above is taken as a basis of design decision, providing construction damage tolerance.

The product produced according to the technical documentation accumulates all technological effects. In this connection despite analysis and synthesis a great number of aspects, approved opinion on mechanical behaviour of construction and recommendations being given only on the base of design models is not always justified for such complex and critical systems as MGB. So study of product behaviour on models and on fullsize units is an obligatory cycle in integration process of product design.

Planning of experiments is based on Common Airworthiness Requirement and state regulating documents, Corporation experience, result of current development, on engineering analysis of construction and units technology special

features jointly with statistical study of MGB and functionally similar products failure.
The program of the experimental investigation determines the body (the minimum preferably) of samples, units and their models of fullsize product deriving from National Standards, "Klimov" Corporation's experience, know-how, the predicted prospect of the design development, the results of the design and analytical works.This program is approved at the earliest stages of the design. Later it enables to extend the field of work as the components are manufactured ahead of schedule.
So, the program is being carried out and extended along with the design development.
The program provides: the test nomenclature, the issue of technical task for each investigation conducting, the issue of technical requirement for the test bench and for its preparation, the issue of working program, conducting of units tests, bench tests and the flight tests.
It also provides justification of the AMETprogram of service life evaluation, if necessary;the development of the test benches and test rigs design support. The program provides test conducting; the issue of reports; coordination of them with the organizations envolved and their approval certificates.
The tests subjects can be defined from the Table . Both the individual components, units and MGB as a whole are the test subjects.
Taken into account the causes of test initiation, as follows:
- the standards;
- the modification of structure;
- the measures on defects;
- the justification of the theoretical models being used;
- the strength demonstration;
- the structure certification -

the different test practice with the use of various test rings equipment is applied.
The basis of the strength evaluation includes the following stages:
- flight tests with the measurement of helicopter accessories loading parameters at all main operational ratings including the limit ratings;
- determination of service life of MGB and accessories with the laboratory test methods taken into account load flight measurements;
- MGB reliability check within the set service life by the operational tests according to the special program drawn up taken into account the helicopter probable flight time at various flight.

The laboratory tests provide the data on mechanical properties of the materials and components, dynamic characteristics of the components and units, on the fine structure of the stress distribution at the points of the components of functionally-forced complicated form. The laboratory tests also give the data on the behaviour of the attaching parts in a joint and the data on the distribution of residual stresses through the operations of the manufacturing cycle etc.
The examples of this kind of tests are given in fig.4.
a - the diagram of fatigue endurance limit determination for gear-wheel rim, (VR -14)
b - the fotogram of isolines pattern in the slots of VR-252 rotor
c - the sequence of specimen preparation to study the manufacturing process effect upon residual stress in AAGB gear.

The examples given above concern the samples (the fragments of components) being used for the tests.These samples are individual during strength development for each gearbox, as well as the procedure of experimental data processing. Here the experience of the organizations of the same profile is extensively used.
At the same time, the simples shape and size, equipment, test procedure and data processing for the determination of mechanical properties are regulated by National Standards. The batch-produced equipment is used for the tests.
The determination of vibration decrement of gear-wheel units composite structures, with the introduced structural dampinrg, may be referred to laboratory study too. Generally, it is not possible to excite such units with the necessary intensity on the vibration testing machines. For this purpose the

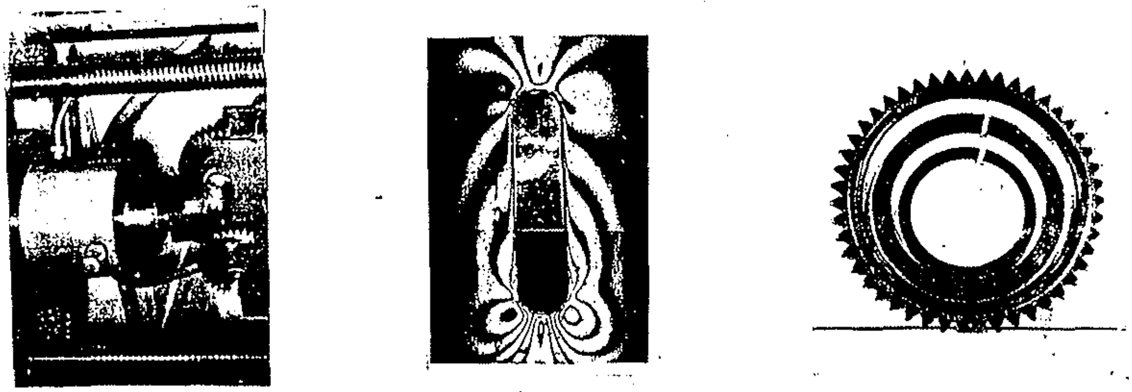

Fig.4

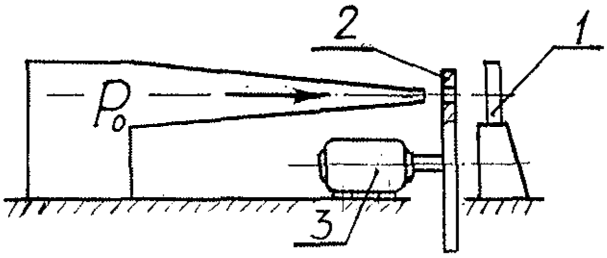

Fig.5

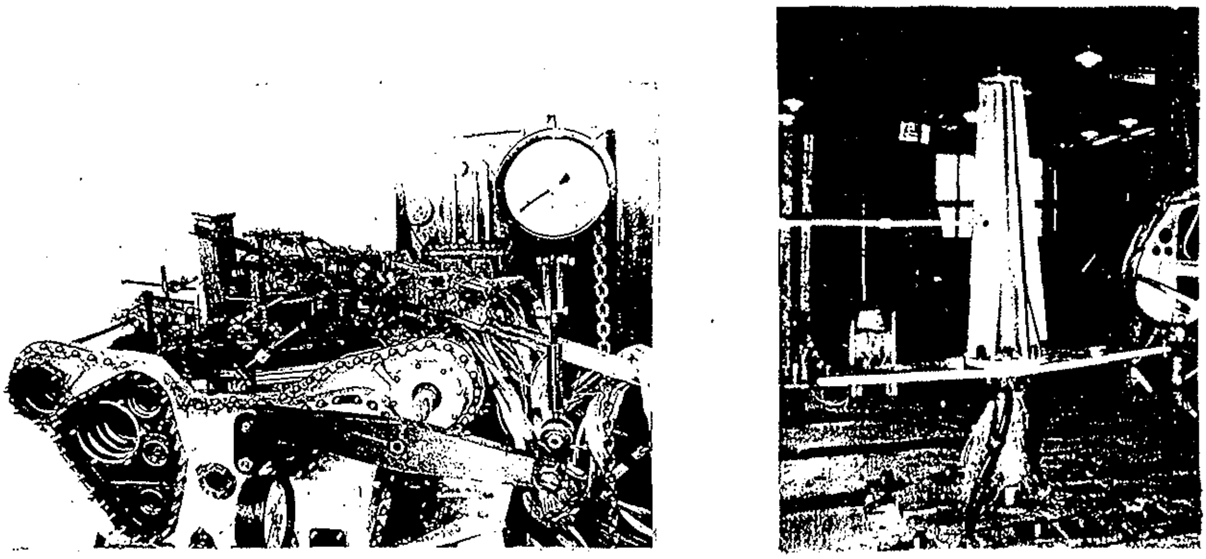

Fig.6

acoustic exciter (air vibrator) is used to apply the high-frequency alternating load.
The scheme of the machine is shown in fig. 5 . The sample is fastened between the grips (1), so that it is in the air stream. The stream parameters are assigned by Po supplied pressure. The frequency acting on the sample is assigned by the stream interrupter which is made in a form of a disk with holes (2). The disk is brought into rotation by the ajustable speed electric motor (3). The disks-interrupters are completed in a set and they have holes of various quantity and size, which allows to vary widely the frequency and the level of structural element exciting. The installation is located in a sound--proof cell and is remote controlled.
Reading the gear amplitude-frequency characteristic at the various damper setting is performed immediately by the stress level in the plane at the various modes of vibration. It should be noted that the bench capacity is sufficient to generate stresses excessing the MGB gears planes' fatigue strength.
Considerable body of investigations is being conducted to study the strength and deformation of the units inoperative and that of the whole unit.
The static tests and the accelerated service life tests at the alternating loads on the vibration testing machines are conducted.
The equipment with centralized control and indication collecting system is used. This equipment is type-designed and is used for the tests of various products.
The displacement transformation indicators with remote source data transfer, strain gauges, thermocouples and as well data recordes are used for measurements. The ptimary static data processing is performed in the course of the experiment. The dynamic processes data are processed by the equipment for digital analysis of quick-running processes.
If loaded, the structure behaviour to the point of failure is studied on the test benches located in the cells or in the static test halls (on the customer's facilities as well) depending on the size of the objects being tested.
Test benches include typical equipment:reinforced floor which permits to attach bearing supports, links and levers system, power measuring system, load system (hydraulic power cylinders joint in the central control system) or in simple cases tender or cargo system.
Such assemblies as gear wheels, casings of gear train,planet pinions casings, poor links, etc. are being tested in the cells. Reduction gear box casings in assembly with transmission requiring greater areas and space are being tested in halls. Typical tooling which is adapted for each specific element loading is used. Loading is conducted by hydraulic power cylinders calibrated by load through links, cross members and levers system. During tests simultaneously up to 20 hydraulic power cylinders might be used which are controlled by the same program.
The stressed state is registed by the automated measuring system which includes sensors in the form of resistance strain gauges, movement - by remote reading indicators.
In fig.6 the load unit of planet pinions casings for VR-252 product is shown.
In fig.7 the VR-252 MGB static test set for VR-32 helicopter is shown.

In fig. 8 VR casing prepared by strain gauges is shown. Gear wheels, shafts and transmission elements are prepared too.
Construction stressed-strained state is determined by two steps at strain gauges location points both as single and joint in rosette-type groups of strain gauges which are located at specific angle to each other.
Matrix of inverter strain resistances values on different phases of construction loading is as follows:

$$N_{ij} = \begin{vmatrix} N_{11}, & N_{12}, & \dots, & N_{1j} \\ N_{21}, & N_{22}, & \dots, & N_{2j} \\ . & & & \\ . & & & \\ N_{i1}, & N_{i2}, & \dots, & N_{ij} \end{vmatrix}$$

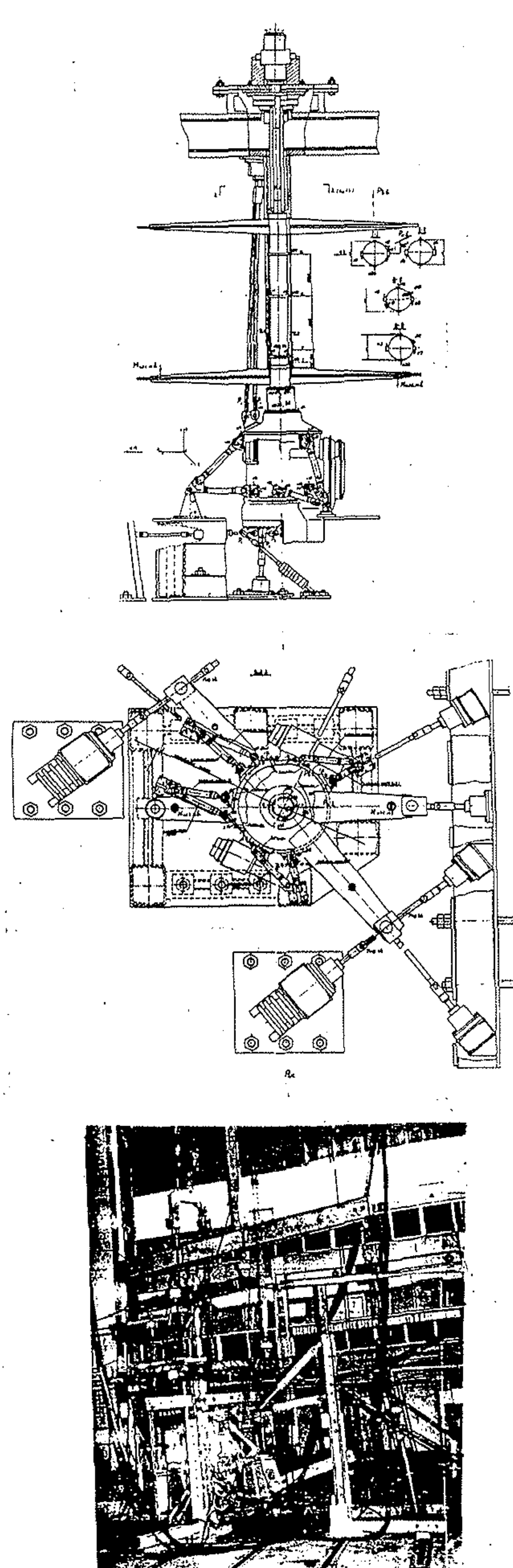

Fig.7

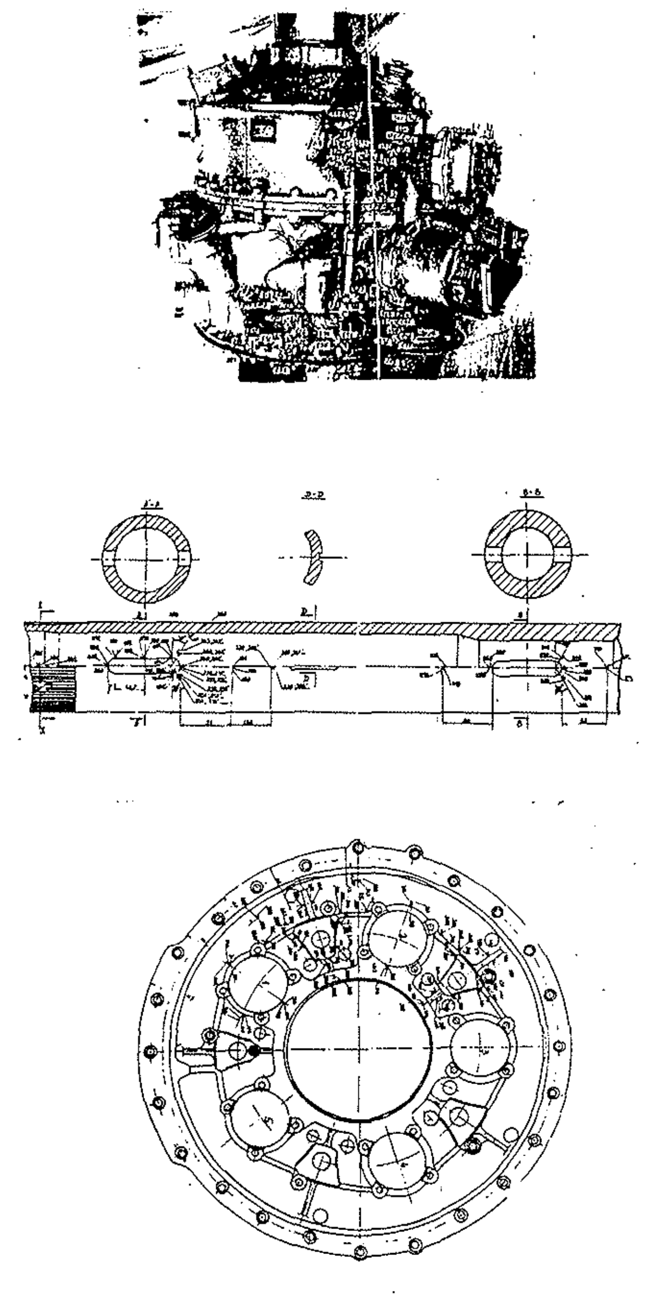

Fig.8

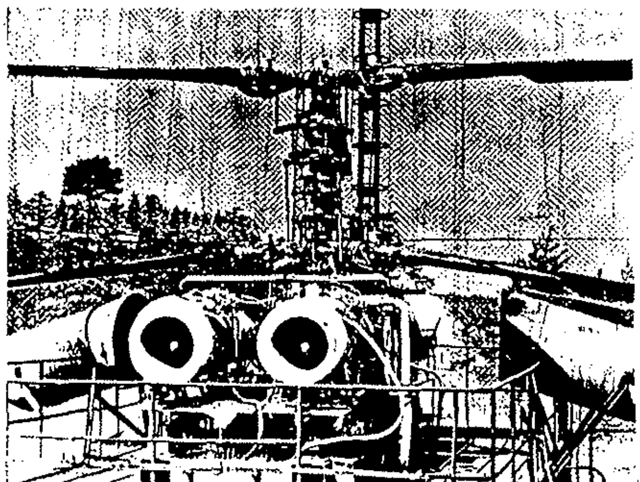

Fig.9

where indexes of optional element Nij have the following meaning: i - number of measure, j - number of loading phase.

Vector-table of load values by loading phases of construction presents as: Fi = F1, F2, ... Fj. The gauge factor of strain gauge K is adopted as a certain constant. Selection of Nj mistaken values by criterion of impossible deviations in reading file (strain gauges break or short circuit) leads to data set, presented by vectors:

N1, N2, ... , Nm
F1, F2, ... , Fm

Then data convolution is being performed supposing the next linear dependence:

$$N = a F + b$$

where a and b coefficients are calculated by square method.

After a and b coefficients have been calculated and data analysis for linearity, the calculation of relative deformation for F load required value is being performed.
In case linear form of data dependence is not proved,the piecewise-linear approximation will be used on the required F load.
Construction manufactured according to Klimov documentation and exposed to loads exceeding the operational by 1.6 to 2.5 times in the most difficult flight cases and in case of control blocking - by twice, demonstrates the absence of residual movements and rotors shafts stability preservation.
Vibration durability tests of full-scale units are conducted on vibration benches. Klimov Corporation has a number of such benches with program control and expulsive force in range of 0.2 -16 t and also mechanical low-frequency vibration bench.
On vibration benches the load value is registed by transmitters which send a signal not only to feedback path of loading control but also permit to record using load continuously, which increases precision of the given loading program performance and experiment.
Durability tests of VR-800 intermediate gear box attaching units might serve as an example of such tests.
Bearings operability is working out during prolonged operating time when operating conditions such as speed, load and lubrications are created at bearing benches.
It should be stressed that for the most critical components not only one, but all the stages of strength treatment are performed.The through shaft of Ka-32 helicopter is such a component.
The last one is a tube structure of variable section with a wall thickness of t = 0.25R. It has stress concentration zones where the structurally necessary through longitudial slots are located. The shaft is subjected to torsional moment action resulting in a complex stress state of the dangerous stress concentration zones.
Because of the particular importance of the component we determine the actual shaft resistance to loads.
For this:

- The strength and life analysis were carried out.
- The shaft was checked up by the analysis and strain measurement for the possible resonance of the connected torsion system.
- The shaft was checked up for the absence of bending resonance by the analysis and strain measurement.
- Stress distribution along the contour with various slot parameters on the photoelastic models at different types of loading was revealed.
- Residual stress fields were determined brought about by hardening treatment with microballs.
- Stresses in operational conditions were determined by the strain measurement on the open test bench.
- The same was done in the flight.
- Fatigue limit margin was determined in respect to the action of limit differentiated moments considered to be the special feature of coaxial rotor helicopters.

- The minimum margin for the ultimate load was determined by the tests incorporating the full-size gearbox.
- The shaft was checked up by service life tests on the open test bench.
- The shaft was checked up on the helicopter during the flight tests (shaft operating time).

The margins on boundary points of construction junctioning are being revealed after laboratory investigations and tests of inoperating constructions.
The durability check of designed model is a finishing test of new MGB serviceability under working conditions. The check is being carried out on test benches and the helicopter.
Endurance test benches are accomplished in the form of arrangements with full simulation of all power plant accessories, fixtures, conditions to helicopter and to each other, and they are equipped by the remote control system with use of programmed load automatic device. So, power ratings specified cycle is being simulated.
Fig. 9 - the view of open test benches.
a)Power plant of Ka-32 helicopter.
The test benches give an opportunity to simulate the loads approximated to those in flights during the process of power plant endurance operation and to study the internal excitation in an engagement depending on the factors which determine the dynamic components of load.
Strain-gauging on the test bench allows to add the controlled changes.
As a result of these works it is known that depending on engagement disruption ratio - undesigned contact spot, clearance in engagement, stiffness disruption of rim-plane system in composite gears - forces, consequently,stresses are changed by 2 - 4.5 times.
Introduction of damping into gear reduces stresses by 4 - 6 times.
This information allows to work out well-founded requirements and criteria of construction and engagement assembling.
Simultaneously we can draw up the image of gearbox vibration by the results of airframe vibration recording in the standard points. As a rule, this is the area of gearbox inlet.
Frequency range of measurements include the lowest frequencies, which are provided by the shaft rotation, and high-frequency spectrum components recoupling of pair of gears.
While working out the endurance test program, which makes up the substential part of total expenses, the aims of time and expenses saving are imposed.
Starting 1976, our factory jointly with CIAM worked out the principles of equivalent test reducing by the means of using only the forced ratings with preservation of all the transitional processes.
Comparative tests have shown, that the function of τ rating time to failure with ε rating parameters of its functioning does not change during transfer from ε_0 to ε^*, which allows to exersize recalculation of the test time $\tau(\varepsilon_0)$, at nominal rating during ε_0 maximum rating test time $\tau(\varepsilon^*)$ with increased loads.
The accelerated tests program equivalent by endurance damageability is drawn up on damage linear summation concept:

$$\sum_i^c \frac{t}{T_i} = 1$$

where t - operating time
T - limited durability at i rating.

Also the availability of the left part of the contact endurance curve is taken into account in the following form:

$$N \tau^m = const$$

where m - exponent of contact endurance curve
N - limited durability
τ - long-term contact fatigue limit.

The statistical origin of the contact stresses is also taken into account. Damage probability arising at unsteady ratings operation is exactly simulated at the expence of preservation of these ratings in the test program.

Conclusion.

The design of MGB as a part of helicopter power plant is constantly udging on designer to develop the analytical and the experimental procedures of design. Not only the conventional analytical and experimental procedures but special design expedients are used in strength provision practice directedly. At present the works on integrity are being conducted by means of system co-ordinating of analytical and synthesis issues in the frames of the blocks of strength parameters development included in automatic design system to produce the structure with set service life taking into account maintenability. The efforts being made to receive the positive reports concerning the products operation will include:

- The development of multivariant analysis practice covering the wide range of structural parameters which form the basis of the design decision optimization.
- The constant filling up analytical models banks for units with new structural diagram or those being used at new conditions.
- The analysis deeping by the extension of analytical simulation to new features of the component (structural) use and the new types of stress concentrator.
- The changing to design procedures predicting dangerous consequences. These procedures minimize dangerous consequences by means of the development of design decisions preventing or eliminating these consequences.
- The wide use of standard tests program.
- The filling up and the systematization of the data on materials mechanical properties on components connection and on the procedure effect on components behaviour.
- The experimental methods always prove the design results.

For the last decades the numerical models are being extendedly used for the assistance in the design.
Now we have entered the stage of design expedients application where the analytical models and the activity on structural decisions synthesis are integrated in a single process of parametrical design.