MODERNISATION AND SAFETY INCREASE FOR MI-8 HELICOPTER PARK FOR 30-YEAR COMMERCIAL PRODUCTION AND OPERATION

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INTRODUCTION

The paper considers some essential aspects of engineering support for serial manufacturing and operation of Mi-8 helicopter family, being one of the most mass productive in its class.

For more than 30 years of Mi-8 helicopter family has been operative in the market a significant reevaluation of the requirements for the safety level, service life and comfort happens to occur. The actual standards have arised a number of supplementary problems for designers to solve, moreover the solution should take into account both the demands of a huge operational park and the increased requirements. Thus rotorcraft longevity is closely tied with the perfection and modification aspects.

The paper presented embraces some of the problems, dealing with oscillation, strength, safety and comfort of rotorcraft, which has been solved within the frames of engineering support.

One of the chapters gives some data obtained in the process of tail rotor modernisation and increasing of its efficiency, following the addition to the engine power from 2200 Kw to 2800 Kw and consequently the flight height capability for the Mi-8MT and Mi-17 helicopter type.

The paper also considers two cases identified as " maturity decease" which appears long after the initial serial operation of rotorcraft park. The decease occurs either as a result of operational conditions or as an appearance of nonaccounted both technical characteristics and material properties dispersion. The causes have been identified under the analysis of destructions occurring both in honeycomb and blade tail section.

Another case considered deals with rotor blade dynamics when the blade strikes the hub rest. Here we observe the abnormal bending in the tip of blade and the strike of blade at the tail boom. The paper displays the results obtained in the investigation of elastic blade oscillation belonging either console or hinged mode with alternative boundary conditions depending on blade flap deflection angle. The reason for this paradox have been explained and the recommendations given.

The existing trend for vibration level decreasing resulted 4-5 times reduction of helicopter vibration through the 30 year period. For the Mi-8 family being in operation so long some supplementary researches were desirable and actual to ensure the modern level of requirements. Some data resulted from the investigation are given in the paper also.

TAIL ROTORS AND JAW CONTROL PROBLEMS

Heading control and tail rotor problems have always been of major importance among those dealing with Mi-8 helicopters family. Initially while developing 5-blade main rotor we realise the limits of B-531-X3 tail rotor having been a reliable unit for Mi-4 helicopter. The perspective of its forcing proved to be conditioned by a small pitch control margin to the resonance with the second harmonic of Coriolis forces. The similar problem has already appeared in the case of Mi-4, Mi-6 and Mi-10 helicopters design. To solve this problem we have chosen the 3-bladed design for the Mi-8 tail rotor with a universal hinge of the hub and a transmission shaft. The advantages of the scheme are the following:

1. A universal hinge permitted constant angular speed in rotor blade owing to high inertia of the rotor and very small torsion stiffness of a transmission drive shaft. The construction has provided conditions of uniform rotation for the tail rotor similar to that of a cardan hinge with constant transmission ratio, which practically eliminated Coriolis forces.

2. Flap hinges loaded with centrifugal force and alternative loads were of no use, which is an obvious advantage because the level of hinge loads is known to be of the same order as the similar loads on the main rotor blades and hub.

3. As far as the loading in the flap plane is concerned the rotor under consideration is practically equivalent to that with individual flap hinges. The first and the second harmonics cause loading at hinge modes and only the third one arises from console loading.

The rotor developed was original in essence and had not had any analogy. It still remains unique. The only unit taken from the predecessor rotor was the axial hinge ball thrust bearing. But nevertheless this particular unit appeared to be the most inadequate although it had worked perfectly in the previous construction under a similar loads level. The reason for abrupt decreasing in life was a rotor parameter known as a flap regulator. It provoked oscillations in the axial hinge which had not been the case in the predecessor. Such an oscillatory mode when the balls move along a small part of rolling road (3...5 mm) resulted in a fast balls wear and pitting of the rolling road.

The solution of a rotor modernisation problem was obtained owing to the application of a two-row roller thrust bearing, the separator window geometry and the roller axes tilt in it enabled the roller circulation and even filling of the surfaces with contacting sectors. The inclusion of a lower stiffness section between the root and feather part of the blade modified the blade significantly which compensated stiffness increasing of the axial hinge construction and held console lag mode frequency below the 2-nd harmonic of external loads. The rotor of the described modification has been in production till now.

For a long time a problem of major importance kept being the increasing of flight altitude and respectively heading control reserve which showed itself obviously at altitude flight with an unfavourable wind direction. As alternative designs to the serial one a rotor with lag hinges and later a so-called "semi-rigid" rotor were designed. Moreover along with the thrust increasing the problems of decreasing in a load level and weight as well as rotor resource increasing found their solutions. The way to the general solution was very frequently furnished with the necessity to solve a number of concomitant problems involved. So in the case of rotor with lag hinges there appeared an insurmountable problem in mass fabrication technology and in stabilisation of elastomer mechanical properties for elastic interblade elements although experimental rotor showed high efficiency.

A semi-rigid rotor with flap hinges and the first lag console mode frequency position about "1.5 p - harmonic" of load yielded an unexpected effect - "chord flutter". The investigations aiming at the solution of chord flutter problem involved tests of the rotor construction with a negative value of flap regulator ratio. Analytical and experimental investigation resulted in the elimination of the problem. Nevertheless despite the obvious advantages of the rotor considered the higher labour requirements for the manufacturing became decisive. The preference was given to the commercially manufactured rotor.

The following modifications were adopted for the serial production. Thus a flag chord was increased up to 0.305 m (the former having being 0.27 m) with conservation of a blade beam technology and configuration; the axial hinge bearing was modified to increase its load capacity as far as the blade centrifugal force was consequently increased; the control system elements were strengthened to increase a blade alternative pitch moment.

The other researches aiming at the contribution to the extension of altitude capacity and yaw control margins were conducted to investigate the rotor efficiency taking into account the tail rotor aerodynamic interaction with main rotor and a body of a fuselage. The particular target was to explain some anomalous cases of yaw control loss. Mostly such cases occurred at Mi-24 helicopters where a tail rotor with a universal (cardan) hinge was used. The anomalous effects appeared while hovering with a wind flowing from left or manoeuvring near the ground at large values of tail rotor pitch . The effects emerged in the form of yaw rotations which could not be ceased even at pedal extreme position on stop.

The flight investigations showed a considerable affect of main rotor wake on tail rotor efficiency. The major factors of the affect were wind speed and direction as well as tail rotor rotation direction.

Fig. 2 shows the results of the investigation which display the actual opportunity to extend yaw control margins by about 3...5°.

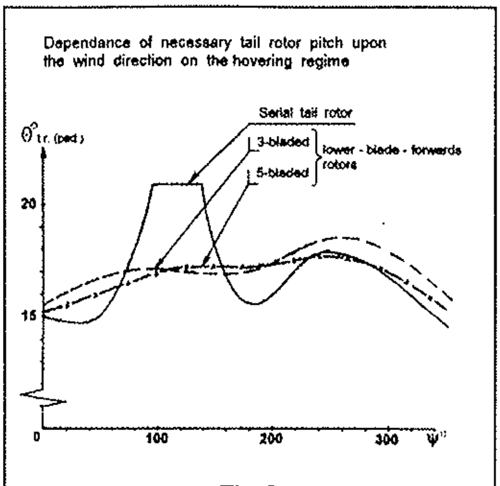


Fig.2

A rotor rotation direction having been used so far, a lower blade moving backwards (against flight direction) coincided with a main rotor wake circulation which resulted in the decreasing of relative flow speed around a tail rotor blade profile and consequently in the decreasing of rotor efficiency.

Particularly this effect manifested itself near the ground with a growing of a main rotor wake speed. The latter deteriorated the case for Mi-24. Mi-14 and Mi-8MT helicopters were modified to take the advantage of the results having been obtained in the cause of the investigation. A pusher type tail rotor was modified into that of a tractor type and was moved from the right to the left side of a fuselage. The rotation direction was altered and became "lower blade goes forwards along a flight direction". Tail rotor transmission was also modernised.

The significant reduction in loss of control margins which was obtained owing to augmentation of tail rotor control ropes tension is worth emphasising here.

So the following modifications have been brought unto the rotor construction:

- increase in rotor solidity (B=0.305 m);
- reverse of rotation direction;
- reduction in loss being a result of control system elasticity.

The modified rotor has enabled to increase engine power, altitude and load-lifting capacity for Mi-8MT type helicopters.

While seeking for the solution how to extend the yaw control margin we came across a problem of a construction weight secondary growth. The additional feasibility of the rotor for hot temperature and higher flight altitude conditions provoked simultaneously the risk of greater loads in going to low temperature conditions. The flight conditions were not expected to demand the high rotor thrust values but if there were the case the strength of tail boom, transmission and control system should be increased, which would certainly entail weight growth. The application of adaptive devises solved the problem. There was developed an additional device SMLC-52 (a System of Mobile Limits Control) installed in the control system which varied yaw control limiters position depending on temperature and flight altitude (fig. 3). Thus the tail rotor was limited in its capacity to thrust and the construction weight was kept at the previous level.

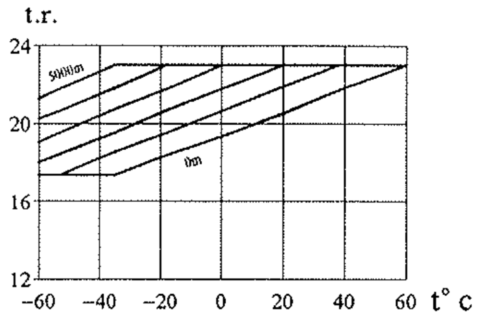


fig. 3

The increase in tail rotor thrust and power naturally resulted in alternative loads and stress growth in parts of the aircraft units. To keep the construction life-time either at the previous level or even to extend it a package of measures was developed. Among them were: smooth thickness distribution in blade spar and lug walls, strengthening of details exterior surfaces. The most loaded area of a tail rotor blade is the last row of a root tip bolted junction with a blade spar. The life-time of this section increased after the installation of bolts with angular gap between its own surface and the surface of a spar hole. With such bolts we managed to eliminate fretting corrosion and consequently the surface was strengthened. The life-time of the section was increased by an order greater. The results of the blade units tests are shown on fig. 4.

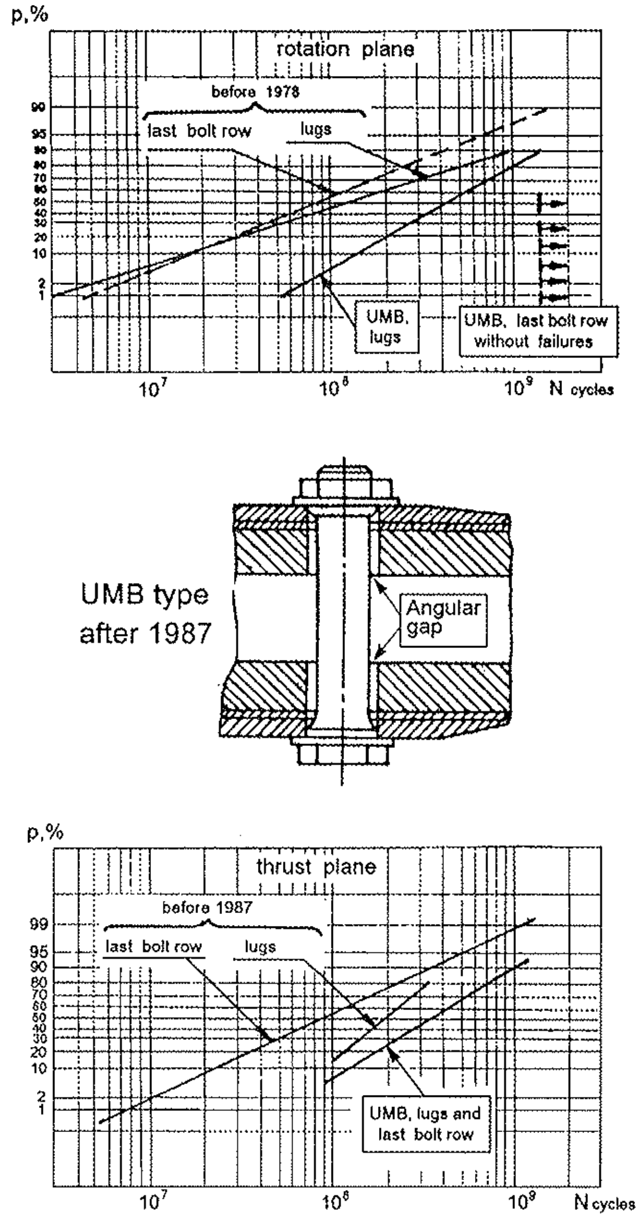


Fig. 4

TECHNICAL AND TECHNOLOGICAL SUPPLEMENT FOR THE SERIAL PRODUCTION AND OPERATION

The major element of a designer involvement into the commercial manufacturing and operation is to provide the stability and quality of the processes. The complex task comprises:

- flight tests to monitor measurements of loads accounting for the constructive or technological modifications in an aircraft manufacture;
- control and serial tests of semi-products (input monitoring), laboratory material sample tests, static and complex fatigue tests of full-scale products and units;
- improvement of test methods to take into account the combination of major damage factors, testing of units and samples having been in operation;

- studying of destruction processes and development of non-destructive monitoring methods;
- improvement of fatigue damage estimation methods and those for life-time specification.

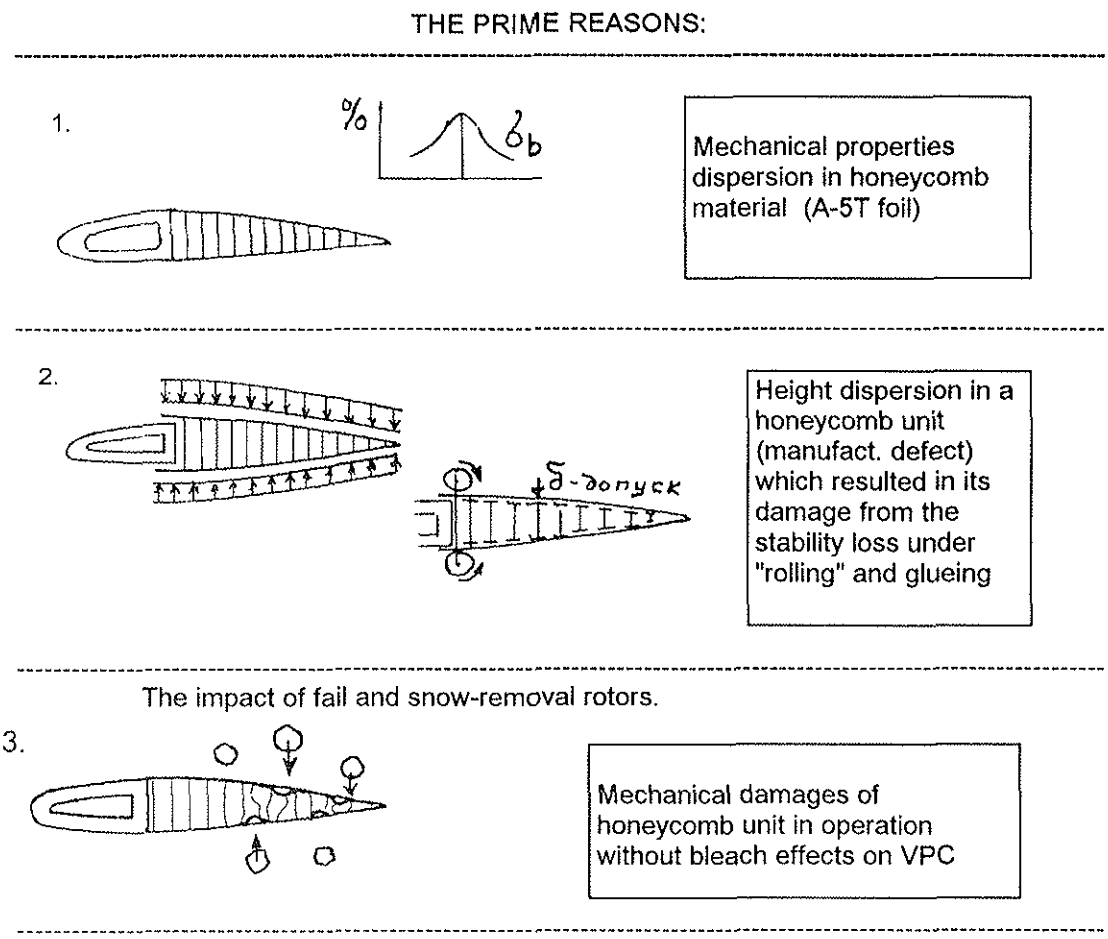
Occasionally new problems attributed to varying manufacturing or operational conditions emerge.

To illustrate a complex problem involving the essential elements of design, technology, manufacturing and operation factors two representative examples will be given below.

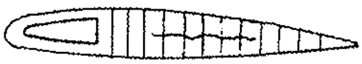
The first case deals with a serial production and operation of a certain helicopter model for a decade. The long manufacturing period gives the opportunity of stabilisation in technology, nevertheless some inexplicable tail rotor blade feather destructions occurred. For more than a year we spent on the discovering of the defect, the measurement of internal pressure pulsation in blade honeycomb unit being among the methods applied. About 30 faults were detected and analysed during the period, among them were either feather section destructions or honeycomb unit damages moreover the external vanish and paint coating (VPC) and skin did not show any signs of breaking up. Fortunately no serious consequences followed including the case when the destruction occurred at the 800 m altitude and resulted in the blade section and reducer breaking up. However a tragedy was avoided. The investigation detected the defects in both honeycomb filling material and feathering unit manufacturing technology. As well some operational damages of honeycomb unit (see fig. 5) were also discovered.

The shortcomings in technology came to the surface when the new snow-removal rotors come into use. The affect on the rotor blade is shown on the picture presented.

Fig. 5:



RESULTS:



1. Fatigue destruction in honeycomb unit walls without displayed damages in VPC.

2. Partial or total blade feather unit failure

MEASURES:

1. AMG-2N foil took the place of A-5T.
2. The manufacture allowance for honeycomb unit height was reduced.
3. Additional notes on methods for the occasional control tests and on probable damages occurring while actual operation.

That was the time when the term "actual operation conditions" came into use which seemed to embrace the effect of modernised snow-removal rotor machines on helicopters (fig. 6...7). The honeycomb unit damages rooted in technological and operational defects showed themselves as a loss in stability or as wall cracks and were undetectable on the coating but resulted in burst honeycomb destructions. The essential changes were introduced in industrial technologies, particularly the allowance area was reduced, AMG-2N foil took the place of A-5T. The effect was an availability of foil mechanical properties input monitoring. The efforts undertaken brought the desired result: the problem was localised and removed.

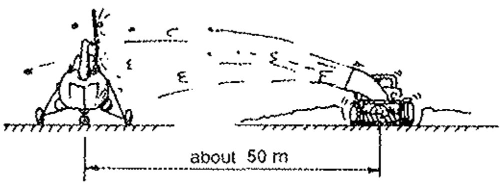


Fig. 6

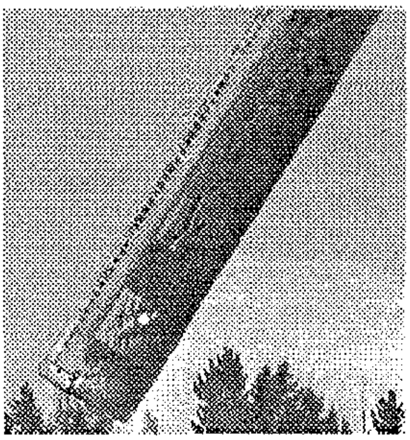


Fig. 7

The second case deals with a main rotor blades hit against a tail boom. The growing number of "boom cut off" incidents kept occurring in the last year of a decade large scale operation period. The control system kinematic analysis within the frames of the investigation revealed the allowance area for control stick position limits, auto-pilot servomechanism paces and hydroactuator paces to be inconsistent so that a certain expansion of the total blade flap motion margins could be possible. Nevertheless even taking into account the above the clearance between blade and tail boom was expected to be about 0.3 ... 0.5 m. The tests on harness and landing with forward run gave even greater clearance value - 0.5 ... 0.65 m. The solution was found after a scrupulous analysis of a flexible blade motion, the blade contact with a flap rest of a hub being taken into consideration. This contact proved to have occurred long before a blade probable contact with a tail boom. The designed clearance given above was obtained from a static balance calculation considering a hinge-mounted rigid blade oscillations. In case when the blade strikes the hub rest and turns into a console-mounted beam such a calculation becomes senseless.

The calculations for a flexible blade model displayed a blade tip deflection to be greater then in a case of strikeless blade motion (that is with no hub rest). Such an inconsistent result was firstly ascribed to the calculation errors. However the investigation proved the result to be true and the problem had been in finding of a consistent interpretation. The correct explanation of the phenomenon is the following. Although a flap hinge limit produced the resistance to blade motion but simultaneously a pitch flap compensator was shut off, which function was to restore the moment caused by aerodynamic forces (so-called aerodynamic stiffness). In no aerodynamic stiffness condition the further movement of the blade (after the contact with hub rest) was not compensated by additional hub limiter resistance and by blade flexible resistance. As a result blade sections deflections got greater (fig. 8). The deflection deference was equal to 0.3 m to compare with a blade strikeless motion. Fig. 9 displays the result of the analysis and experiments

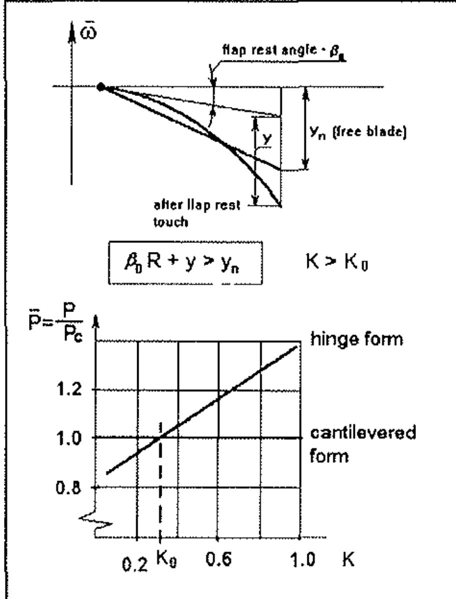


Fig.8

The clear understanding of the phenomenon provided the exact and reliable measures to be taken. A swash plate limit to back was reduced by 0.5° and a limiting condition for swash plate deflection was introduced particularly an additional force on control stick when a helicopter is on the ground warns a pilot to act with care. In flight the restriction is removed enabling the employment of full range longitudinal control and manoeuvring properties

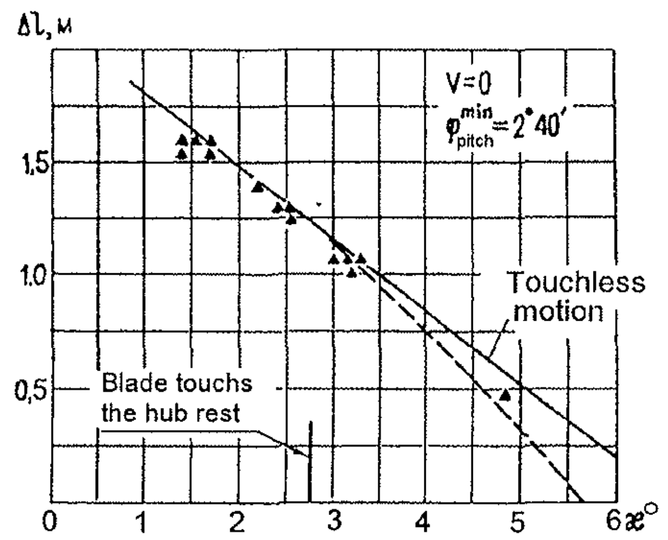


Fig. 9

The joint efforts of the investigators and engineers resulted in a very significant increment in Mi-8 helicopter operational reliability. Still the question remains: why the "disease" has been waiting for 10 years to appear? Why did not it show itself at the initial stages of operation? Moreover the helicopter parameters pertaining to the described phenomenon kept being unaltered.

The key reason for such a "delay" could lie in an extremely important sphere involved in helicopter operation, so-called "human factor". In fact the growing confidence in the helicopter reliability seems to deaden the crew and staff alertness. The natural consequence of such a circumstance appears to be more hard conditions of employment and application. In the first case described above we came across the similar problem. The situation development analysis showed that prior strikes upon tail boom had been the strikes upon the limiters of flap hinge which should have been a natural restriction to further stick movement. Nevertheless the experience shows the natural expected reaction does not follow because either the flight situation dictates the behaviour manner or the acquired behaviour stereotype does not consider the strikes upon flap hinge limiters as alarming.

VIBRATIONS AND COMFORT

The problem of vibration reduction proved to be extremely important in the development of the first version of V-8 helicopter with 4-bladed main rotor in 60-s. The efforts to get vibration level below 0.6 ... 0.7 g were not a success. The helicopter was reconstructed, a 5-bladed main rotor version was adapted. It was called Mi-8. The vibration problem was solved for the time being. But in the middle of 70-s it came into being again as the primary issue to provide a smoother ride on Mi-8 helicopters. The growing operated helicopter fleet, new modifications, the origination of passenger helicopters and their VIP-variant of "Salon" type, the achievements of competitive foreign models - generates a new approach to comfort among the operators. The most sensible group of operators was civil aviation fleet pilots who had used to flight about 1500 hours a year (the mean crew flight hours rate was about 80...100 hours a month). The legislative standard for the vibration level was determined in a document named GOST 23718-79 issued in 1979. Due to this document the level of allowable vibration was equal to 0.16 g at 16 Hz frequency. The previous permissible vibration level for Mi-8 had been 0.3 ... 0.4 g. The current standard was sure too hard (fig. 10).

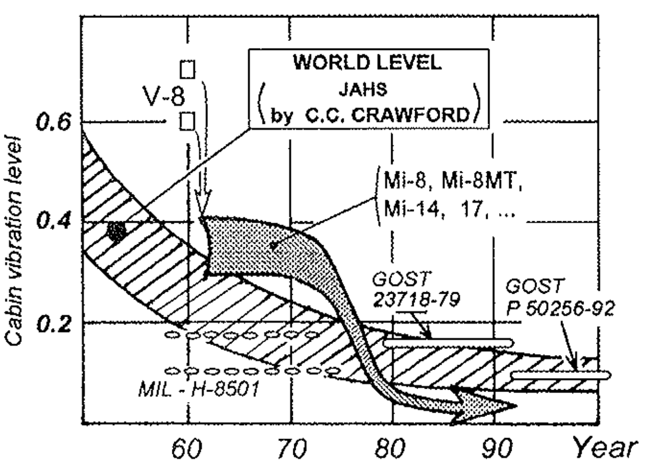


Fig. 10

It was exactly the time when a vibro-absorber for Mi-8 helicopter was developed (fig. 11) a principle of bifilar pendulum being employed in its design.

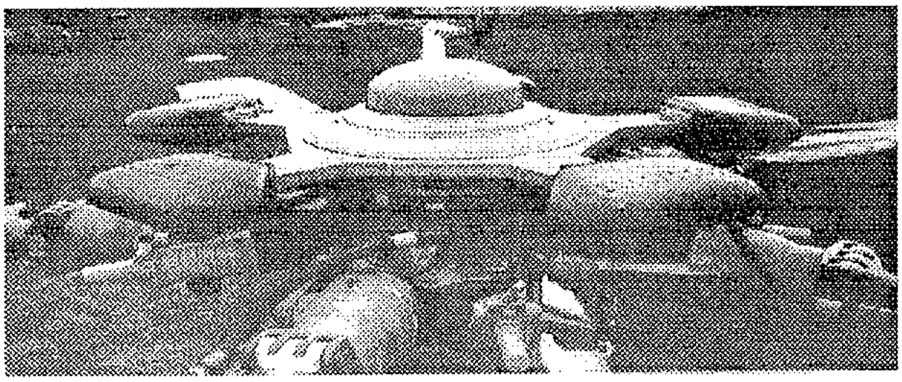


Fig. 11. Vibro-absorber on Mi-8 helicopter.

Factory testing of an experimental prototype showed excellent results (fig. 12 and 13). Actually the vibrations at all flight regimes and in all the parts were reduced significantly. At cruise and dash speeds vibration level did not exceed 0.05 ... 0.1 g. The tests proved it to be below a sensibility threshold. The official tests having been designed originally only for "Salon" version were extended for a transport version and confirmed the expected results. The entire routine bureaucratic formalities involving technical documentation, experimental specimens testing, fatigue life specification for the whole device as well as for the units having a life-time depending on vibration level (transmission frame, fuel and oil tanks and the like) were arranged within the reasonable time. The patent was registered four months earlier than the similar US one and a year earlier than the American patents registered in Great Britain, Germany and France.

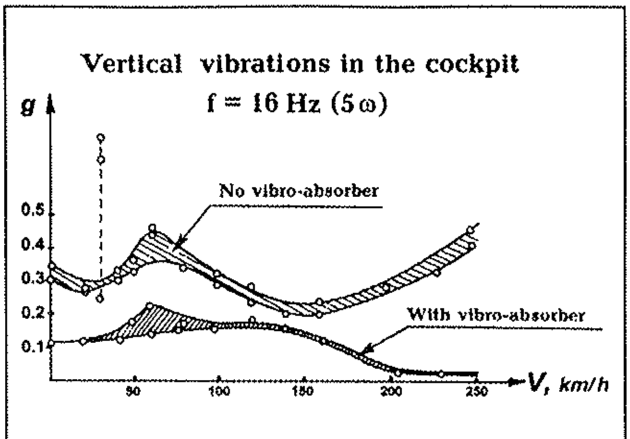


Fig. 12

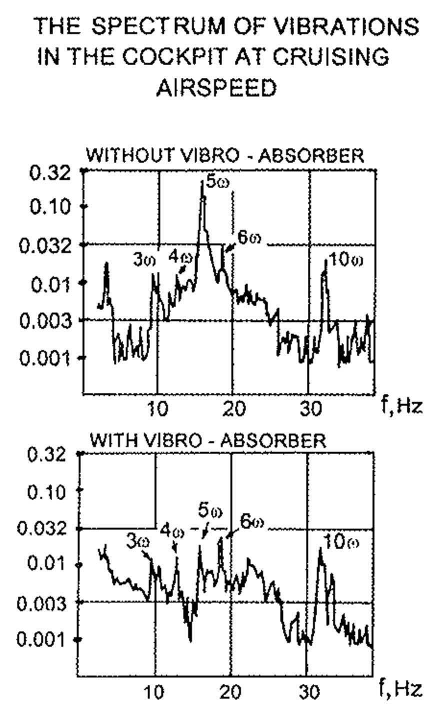


Fig. 13

Major obstacles emerged at the stage of a serial production initiating. The manufactures estimated financial expenditures for a supplementary device as being non-profitable. The actual users were of great help to overcome the manufactures opposition. They appreciated the advantages of comfort within no time. The benefits of the vibro-absorber were the following: 1.5 time reduction of tiredness; more accurate ability to read the pilot cabin instruments scales, prolongation of a crew efficiency for 2 hours; two times reduction in a number of avionics failures. The total effect was more safe flights and lower operation costs.

The "cost" for comfort and some units and equipment longevity was only 0.8 % increment in normal gross weight (GW) and 0.7 % in maximum GW. Favourable weight of pendulums was about half of the device gross weight. The commercial production started in 1981. Since then this unit has had a stable market. There has been manufactured about 2000 units.

Fig. 10 displays the trend of Mi-8 helicopters development and estimation of vibration level for the period from the initial production up to the present time when the vibro-absorbers were installed on Mi-8. The data were collected by prof. Crawford and presented in his contribution delivered in 1989. The data collected embrace the experience of the world helicopter construction involving the Mi-8 vibration level before and after the installation of vibro-absorbers. The leading position of Mi-8 helicopters family is worth emphasising. Similar data are given for Mi-8MT and Mi-14 helicopters. These versions are also supposed to be equipped with such devices.

The vibration problems were associated not only with the 5-th "pass" harmonic of the main rotor loads. Particularly various investigations of helicopter in-plane vibration at frequency 4.5 Hz called in Russian "подсев" (spilling through a sieve) has been conducted. The results obtained provided the vibration identification method and a system of evidences proving the vibration to be of buffet origin. The local nature of the vibrations was identified and there were received some methods to eliminate them.

The other objective of the investigation was low-frequency (3.7 Hz) vertical vibrations. The evidences obtained have traced the origin of the phenomenon being a result of either pilot or auto-pilot involvement into the oscillation loop. It was proved the vibration has nothing to do with blades flutter. A supplementary instruction for crew to avoid, eliminate or prevent the vibration has been worked up.

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