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Review of the Transmissions of the Soviet Helicopters

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REVIEW OF THE TRANSMISSIONS OF THE SOVIET HELICOPTERS

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SUMMARY

This report contains a review of the following aspects of Soviet helicopters transmissions: transmitted power, weight, reduction ratio, RPM, design configuration, comparison of different type of manufacturing methods, and a description of the materials and technologies applied to critical transmission components.

The report includes mechanical diagrams of the gearboxes of the Soviet helicopters and test stands for testing gearbox and main shaft. This report also has an assessment of the quality of Soviet helicopter transmissions and a comparison to their Western counterparts.

INTRODUCTION

The Soviet Union is the second largest helicopter producing country and a world leader in the production of large heavy lift helicopters. Power capacity of Soviet helicopter transmissions is typically in the range of 2200 - 23000 HP (1650-17000 Kwt).

In comparison to Western helicopters, weight of the transmission on the Soviet helicopter relative to power is higher; but the method of assessing quality using the ratio of weight to power is not really accurate. If transmissions are compared on the basis of weight to torque ratio, transmissions of the Soviet helicopters look better. In addition, consideration must be given to level of technology, quality of materials, life of service and scale factor. In this paper several aspects of helicopters transmission design in USSR will be addressed. First, the general types of main gearbox configurations used in various helicopters will be described. Lubrication technology will next be discussed, followed by transmission testing approaches. Finally, a description of material technology is included.

SOVIET HELICOPTERS DRIVE TRAIN DESIGN

Design of the transmissions of the Soviet helicopters is different than transmissions of Western helicopters. There are seven helicopters now in production in USSR: Mi-17, Mi-14, Mi-24, Mi-26, Mi-28, Mi-34 and Ka-32. Both the Mi-14 and Mi-17 use a similar transmission; the Mi-14, Mi-17, Mi-24, Mi-28, Ka-32 all have the same power (they use the same engines) but are

significantly different designs. Unique is the Mi-34 helicopter, which has a piston engine and a one stage gearbox, all other Soviet helicopters have two gas turbine engines. The helicopter Ka-32 features a coaxial rotor, while all "Mi" helicopters have one main rotor and a tail rotor. The quality of the helicopter transmissions can be defined by $K = W/T^{0.8}$, where W is the transmission weight; and T is the torque on the rotor. A list of the basic properties of the transmissions of the soviet helicopters include quality is given in Table 1. Quality of the American helicopter transmissions lie between 0.30 - 0.38.

The transmission of these helicopters include tail shaft power take-off gears, sectional tail rotor shaft with articulated couplings and intermediate supports bearings, an intermediate gearbox and the tail gearbox. The same general drive arrangement is also used on most single main rotor Western helicopters. All helicopters use an accessory drive to run generators, oil lubrication pumps, hydraulic control pumps, a compressor, a rotor brake, and a blower.

The kinematic arrangement of the Mi-24 main gearbox is shown schematically in Figure 1. From a western perspective, an interesting feature of this gearbox is the use of a compound planetary final reduction stage, where torque is high and load sharing benefits are appreciable.

The first stage is a spur gear train which combines the torques from the two turboshaft engines. The second stage is a bevel gear train, and the third and fourth stages are the compound planetary stages, with final power take-off to the main rotor shaft.

Another interesting main gearbox design is the non planetary split torque gearbox of the helicopter Mi-26 (Figure 2). In this gearbox, the torque from each engine shaft is distributed to two spiral bevel reduction gears and to the power take-off gear train to the tail shaft. The torque is delivered from four spiral bevel reduction gears to four spur gear trains of the second stage. From these second-stage spur gears the torque is transmitted via eight trains to eight gear pairs which are meshed with two central gears on the main shaft. The gear trains of all three stages are connected by torsional flexible splined quill shafts that assure uniform distribution of the torque along the trains.

The quill shafts have minimum polar moment of inertia for maximum torsional flexibility and barrel shaped splines for compensation of errors of non-coincidence between the connected shaft stage centers. Helicopter Ka-32 has coaxial gearbox with two spiral bevel gear stages, and two counter rotating planetary type stages (Figure 3).

TABLE 1: BASIC PARAMETERS OF THE TRANSMISSIONS OF SOVIET HELICOPTERS

HELICOPTER TYPE	MI-17 MI-14	MI-24 MI-28	MI-26	MI-34	KA-32
ENGINE TYPE	TWO GTE TV3-117MT	TWO GTE TV3-117	TWO GTE D-136	ONE PISTON ENGINE M-14V-26	TWO GTE TV3-117BK
POWER (SHP)	2 x 2200	2 x 2200	2 x 11400	325	2 x 2200
ENGINE RPM	12,000	12,000	8,300	2,800	12,000
ROTOR RPM	192	240	132	390	257
TRANSMITTED RATIO	62.5	50	63	7.2	46.7
GEARBOX WEIGHT (kg)	750	690	3,639		720
QUALITY OF TRANSMISSION	0.32	0.35	0.31		0.38

LUBRICATION AND COOLING SYSTEMS
OF THE HELICOPTER
TRANSMISSION

The purpose of transmission lubrication systems is to deliver lubricants to all working parts - gears, bearings and spline joints - to reduce the friction and provide effective cooling of the parts. Supply of the guaranteed amount of oil to all points requiring lubrication and cooling is provided by gear pumps and a special branched system of channels in which the oil is constantly at operating pressure (50-70 psi). The outflow of oil proceeds through calibrated injectors (nozzles) that are oriented to spray oil to the points of lubrication. There are two independent oil lubrication systems and all lubricated points are supplied by two sprays of the oil.

After the process of lubrication, the heated oil collected in the oil sump has to undergo intensive cooling, which is accomplished by sucking oil through the independent air-oil radiator bathed by air delivered by a fan. There is negative pressure in this external oil circuit to assure that if it is damaged, the oil will not be thrown out of the system.

The oil sump is divided into two compartments - a hot one, into which oil pours after passing through the gearbox and from which it is sucked to the radiators; and cold one, to which oil is fed after the radiators and from which it is pumped to the supply the pressure system. In the internal circuit, oil from the pump passes through fine filters (4000-12000 cells per CM²). The filter relief valve serves as a bypass for oil to the pressure system, passing the filter elements when the filter is

clogged or when oils viscosity is high as when the transmission begins operation under low temperature conditions. There are sensors of the temperature, pressure, level of the oil a metal chip indicator in the oil system.

Synthetic oil B-3V has been used for last years as a single oil for gas-turbine engines and transmissions of the helicopters. B-3V oil contains anti-oxidant and film strength additives, it is stable to 200°C (392°F) and it has high lubricating and cooling power. American equivalent of B-3V is oil MIL-L-23699C.

TEST OF THE HELICOPTER TRANSMISSION

A helicopter transmission operates under great stresses and strains, and all its elements must be highly reliable. For this reason despite thorough calculation, state-of-the-art design and quality production, ground tests are essential. They are conducted to determine how closely the service life of all gearbox elements corresponds to design estimates, to determine weak points, and to improve and update design features before flight tests.

The main gearbox is tested on a test stand with loop-system arrangement (Figure 4). One of two gearboxes used is mounted over the other. The test gearbox is lower, instrumentated by strain gages, thermocouples, proximity probes, vibrometers, thermosensitive point, etc. Information from rotating parts is collecting through the slip rings. The upper gearbox is the "slave" a special, reinforced design. The main shafts are joined by a shaft, and high-speed input shafts and outputs to the tail rotor shaft of both gearboxed are then connected vis auxiliary gearboxed for a loop-system arrangement. The arrangement includes a mechanism, usually a differential train, which makes it possible, to load and unload torque to the test gearbox during the test. Sometimes a revolving clutch with hydraulic cylinders is used for this purpose. The drive of a loop system test stand requires a power input equal only to the friction losses in the setup, that is approximately 13% of the circulating power. Since Mi-26 helicopter has 23,000 installed HP, the power need to drive the test stand is 3,000 HP (approximately the power of a railroad locomotive). Rotation is provided by two high voltage electric motors. The motors spin the unloaded gearboxed until the operating speed is attained, following which the torque loading mechanisms gradually applies torque to the system. In the test arrangement shown in Figure 4, the torque loading mechanism is a differential train equipped with an electric motor and a brake; torque is applied to the system using the brake and removed using the electric motor. For testing, the main gearbox is mounted on a stand duplicating helicopter installations with rubber pads in the struts providing the same degree of rigidity. The gearbox housing is subjected to static forces equal to rotor lift and thrust. Numerous strain gages and thermocouples are installed to the gearbox housing. The filters of the lubrication system of

the gearbox are equipped with sensors that signal the appearance of both magnetic and non-magnetic metal particles in the lubricant. If particles are detected the test is halted and the gearbox disassembled to locate the damaged part, determine the course of the damage and replace the part. Test data are recorded and operated by computers.

Other elements of the transmission also undergo bench tests. Tests of the intermediate and tail gearboxes are carried out with a motor to generator system in which the electric motor rotates the input shaft of the gearbox while a generator is mounted on the output shaft, working as a dynamometer. Current from the generator is fed back to the motor, thus, the only outside power used is to compensate for losses in the setup.

Figure 5 is a schematic representation of a rig for testing the main shaft of the helicopter gearbox. Torque, thrust, and lift are applied to the statically loaded shaft by hydraulic cylinders and rubber elastic elements, and dynamic loading from the rotor is simulated by a rotating eccentric vibration. The system operates at frequencies encountered in flight. The support bearings have the same rigidity as in the helicopter.

The transmission is also tested on a full-scale stand which consists of a helicopter mounted on a tower. With operating engines and rotor, the helicopter simulates flight conditions (without taking off) and all systems are tested, including the transmission.

Test of the transmission system continues, of course, during flight tests. The results of ground and flight test are augmented with data obtained after the completion of service-life flight time, when all elements of the transmission are disassembled and inspected for wear. Such procedures continue to be conducted regularly for new helicopters even after they are in series production.

HELICOPTER TRANSMISSION MATERIAL TECHNOLOGY

Aviation gears are made of alloyed chromium-nickel steels of grades: 12 KhN2A, 12 Kh2N4A, 18Kn2N4VA, 14KhGSN2MrA, 12Kh2NVFMA, 20Kh2MVFA, 16Kh2NVFMB and 13Kh2NVM2F; equivalent american steel alloys are 3310H, 3310, E9310, 4317H, M315 respectively.

Steel grade is selected according to the geometry of the engagement, the temperatures at the working surfaces, and the ratio of the bending and contact strains. The mechanical stress allowables of the steels are given in Table 2.

Table 2

ALLOYS	MECHANICAL PROPERTIES - STRESS MPA (KSI)			
	ULTIMATE STRENGTH σ_B	CONVENTIONAL YIELD LIMIT $\sigma_{0.2}$	ENDURANCE LIMIT σ_{-1} (Base $2 \cdot 10^7$ cycles) CARBURIZING	CONTACT STRESS σ_C (Base $5 \cdot 10^7$ cycles)
12KhN3A	900 (13.2)	700 (10.3)	500 (7.35)	1500 (22)
12Kh2N4A	1000 (14.7)	800 (11.8)	900 - 950 (13.2 - 13.9)	1500 (22)
18Kh2N4BA	1150 (16.9)	900 (13.2)	900 - 960 (13.2 - 14.1)	1500 (22)
14KhGSN2MA	1000 (14.7)	800 (11.8)	900 - 950 (13.2 - 13.9)	1500 (22)
12Kh2NYFMA	1000 (14.7)	800 (11.8)	900 (13.2)	1500 (22)
20Kh3MVFA	1250 (18.4)	1050 (15.4)	900 - 1100 (13.2 - 16.1)	1500 (22)
16Kh3NVFMB	1300 (19.1)	1150 (16.9)	950 - 1150 (13.9 - 16.9)	1500 (22)
13Kh3NVM2F	1200 (17.6)	1050 (15.4)	850 - 1000 (12.5 - 14.7)	1500 (22)

All these steel alloys are subjected to heat treatment, carburizing, nitrating or cyaniding. In recent years, aviation steels have been subjected to electric slag remelting, a process which considerably improves the uniformity and reliability of these steels. Helicopter transmission shafts are made of grades 12Kh2N4A, 18KhN2VA and 40KhN2MA alloyed steels; american equivalents are 3310h, 3310 and 4317M alloyed steels respectively.

Rolling contact bearings are made of ShKh-15 steels which are used to manufacture races as well as balls and rollers; american equivalent is SAE 52100 alloy steel. Cages of the bearings are made of bronze or aluminum alloy.

Most housings for helicopters gearboxes are cast of ML-5 magnesium alloy; american analog is magnesium SAE N500. Magnesium alloy has a foam structure, low specific gravity (1.8 after filling), extreme strength-weight ratio property which is a very important innovation in construction. Magnesium alloy housings are coated by epoxied filler to prevent corrosion and oil leak.

More suitable for larger housing elements is Al9 aluminum alloy. The gearbox housing for the Mi-26 helicopter was made of this alloy by stamping. Titanium is now being increasingly employed for building helicopter gear transmissions, though as yet, solely for parts not subjected to heavy loads.

TRANSMISSION COMPONENT TECHNOLOGY

The materials and the technology for manufacturing the gears, shafts, and bearings of Soviet helicopter transmissions are very similar to their western counterparts. Virtually the whole inventory of machine tools used in Soviet helicopter transmission component manufacture consists of American, British, Swiss, German and other imported equipment. Thus, for example, machine tools and technologies for manufacturing spiral bevel gears purchased from Gleason have made it possible to sharply improve the quality of Soviet helicopter transmission gears. Soviet machine tool industry builds copies of modern foreign machine tools, albeit with a lag of several years and with generally inferior quality. Consequently, the quality of Soviet helicopter transmission components lags behind western transmissions not only because of lower quality materials and technology, but in many cases, because of guidelines imposed by the designers themselves. For reasons cited above, it is necessary to strive to safeguard against potential risks by using lower stress designs compared to those in the west. These inherently heavier component designs are not penalized in an environment in which there is no competition.

A promising alternative to involute gearing is conformal (Wildhaber-Novikov) gearing. This gearing offers considerable advantages over involute gearing, but low quality gear cutting and grinding technology hampered its use in helicopter transmissions. The first and probably only application of conformal gearing to aerospace technology was by Great Britain's Westland Helicopter in the transmission of the Lynx helicopter. In the Soviet Union machine-tool building companies and research labs are working on developing technology for cutting and grinding conformal gearing for helicopter transmissions.

CONCLUSION

Helicopter transmission production in the USSR has more than forty years of experience. The number of gearbox designs in production are limited. Some of them are thirty years old, although during this time improved transmissions incorporate: upgrades in power; new technology; improved components resulting from the best machine tools from across the world; and trained staffs. Current transmissions of the Soviet helicopters have good reliability during their service life and have good weight to torque ratio.

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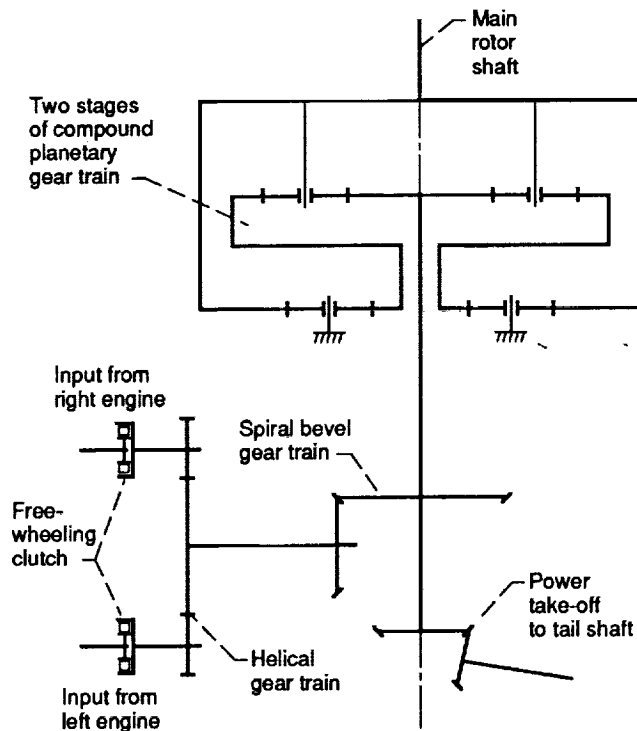


Figure 1.—Mechanical diagram of Mi-24 reduction gearbox.

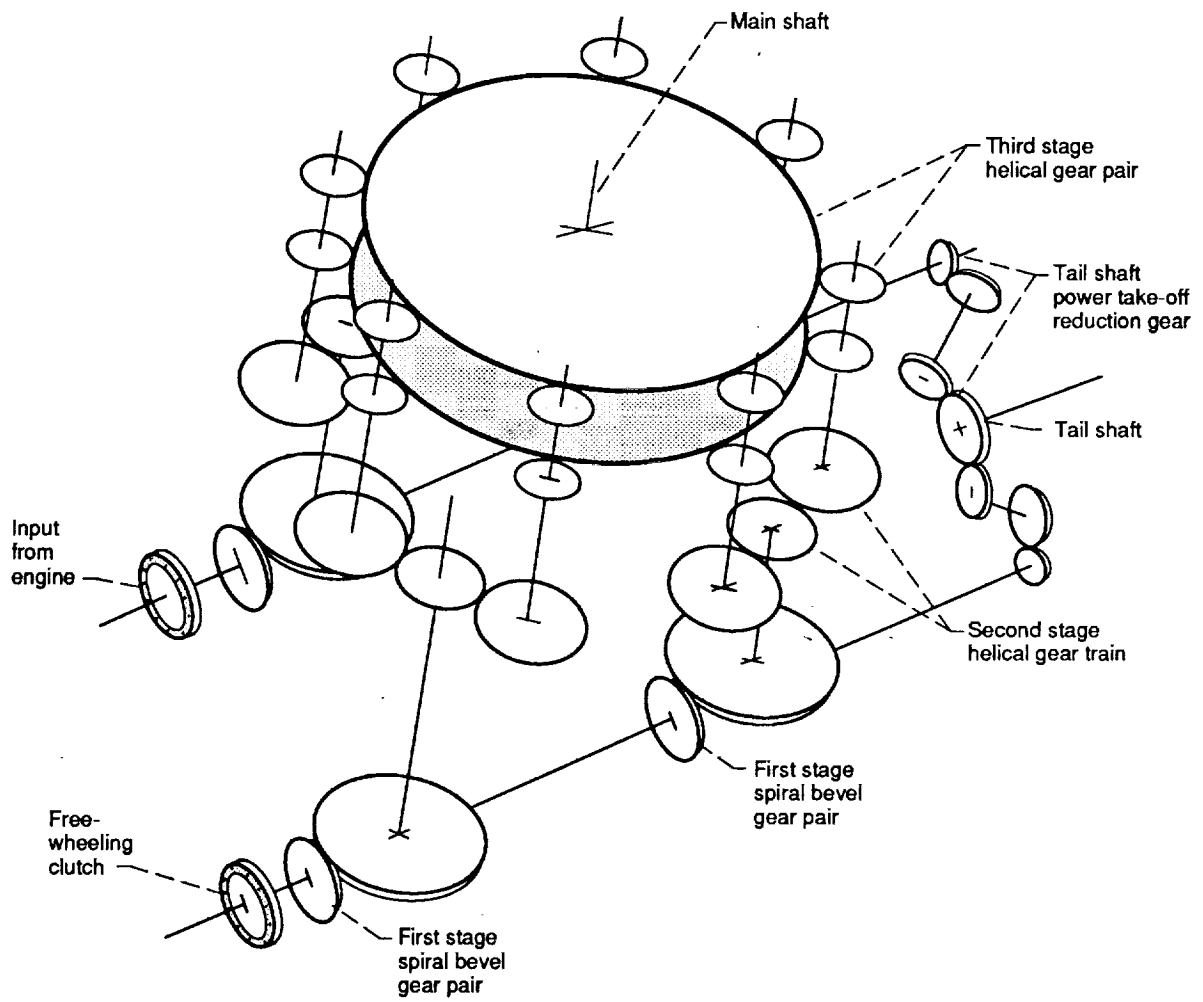


Figure 2.—Mechanical diagram of Mi-26 reduction gearbox.

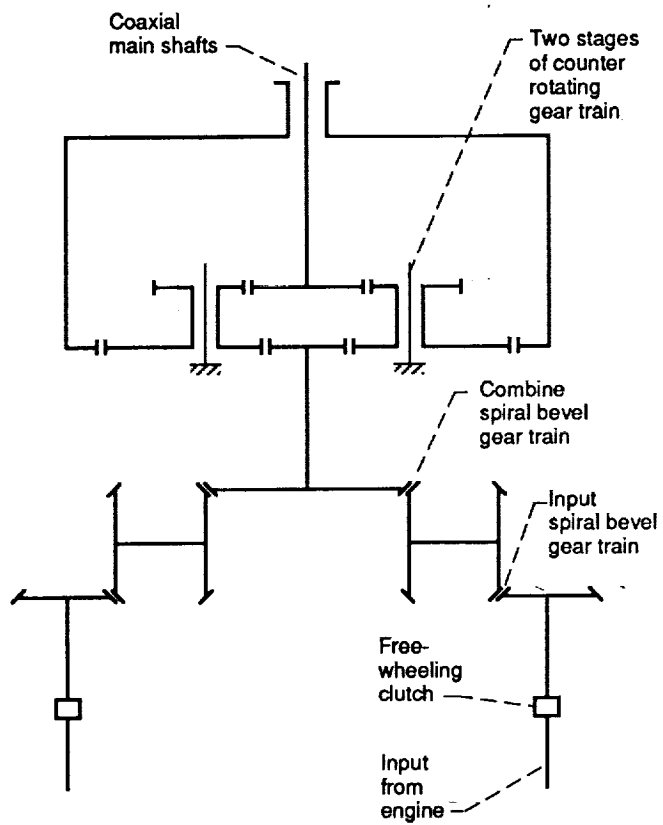


Figure 3.—Mechanical diagram of Ka-32 reduction gearbox.

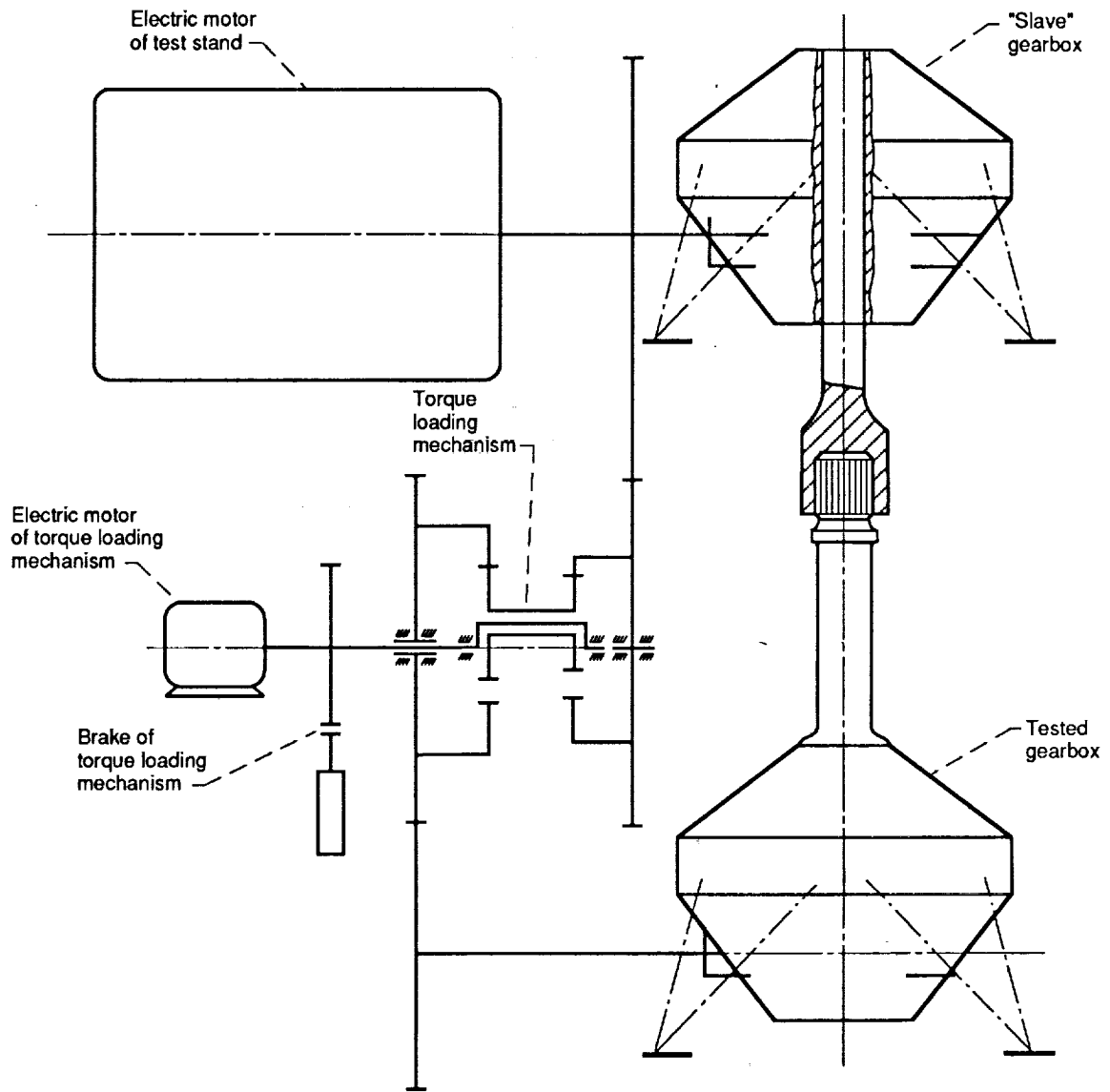


Figure 4.—Loop system test stand for main gearbox.

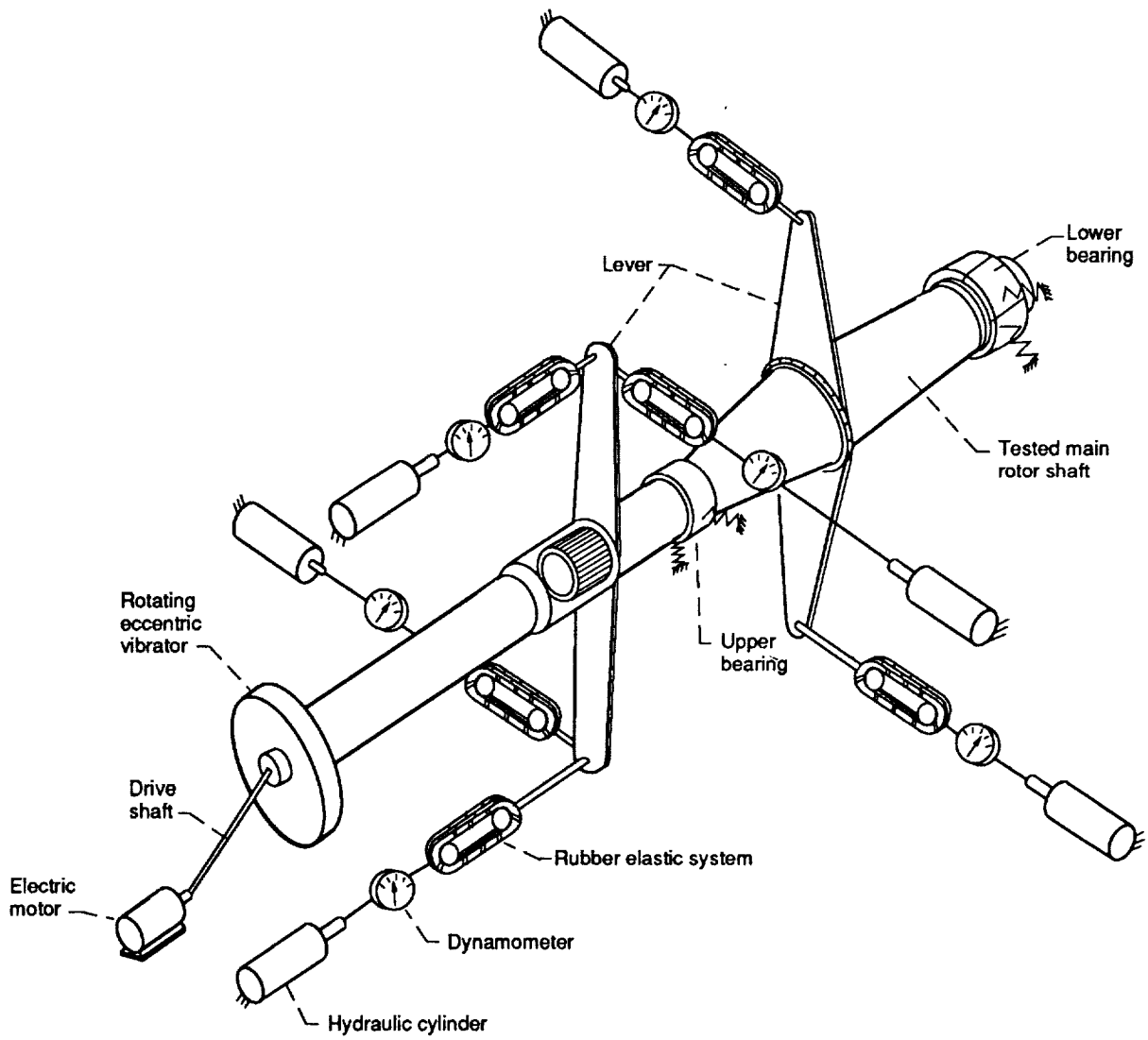


Figure 5.—Fatigue test stand for main rotor shafts.



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