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A COMPREHENSIVE STUDY ON DESIGN STANDARDS FOR GROUND TESTING OF HELICOPTER TRANSMISSION SYSTEM

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Abstract : Transmission system is one of the most important and critical parts of a helicopter. Stringent test requirements are therefore essential to prove capability of the system and thereby ensuring flight safety of helicopter. With this objective, different standards have been defined by military and civil certification agencies. In this paper major system level ground test requirements prescribed in some of the widely accepted standards have been examined and compared. Similarity in test requirements is observed in many cases with a few significant differences.

Keywords : Helicopter, transmission, endurance test, dry run, FAR.

1. Introduction

Helicopter is a flying machine that derives lift from a rotor. In addition to the main rotor, a conventional helicopter relies on a tail rotor for anti-torque and directional control.

To transmit power from engine to rotor, a capable transmission system is needed. The transmission system generally consists of a Main Gearbox (MGB), a Tail Gearbox (TGB), an Intermediate Gearbox (IGB) and a Tail Rotor Drive Shaft between MGB and TGB. Design of this system is more challenging than its counterpart used in industries or ground vehicles due to weight limitations involved in helicopter design.

The transmission system must remain functional even in case of all engine failure or loss of gearbox lubrication to ensure flight safety. To fulfill this objective, different agencies have evolved strict design standards for transmission system. In this paper major system level ground test requirements defined in different design standards have been discussed and compared.

2. Helicopter vs. Automobile Transmission Systems

Power inputs from helicopter engines to MGB are usually higher than that of vehicular gearboxes. Engine powers of different class of helicopters [1-3] are tabulated in Table 1. Similarly Table 2 shows power of different vehicles [4-7].

Table 1 Helicopter engine power data

	R-22	CH-47F	Mi-26
Max. Weight (kg)	622	22668	56000
No. of Engines	1	2	2
Max. Continuous Power (kW)	1x93	2x3529	2x8273

It can be seen from Table 1 and Table 2 that many helicopters have multi engine configuration unlike road vehicles where single engine is normally utilized. Typical arrangement of helicopter transmission system is depicted in Fig.1 through Fig.3. Weight limitation of a flying machine dictates that transmission system should be designed

with high strength to weight ratio. Design of vehicular or industrial gearboxes is not predominantly dominated by such criteria. However, most significant difference is the safety concern involved with functioning of a helicopter transmission system.

Table 2 Road vehicle engine power data

	Maruti 800	Star Mazda	Diesel loco WDM 3A
Max. Weight (kg)	1000	605	> 100000
No. of Engines	1	1	1
Max. Power (kW)	1x28	1x194	1x2325

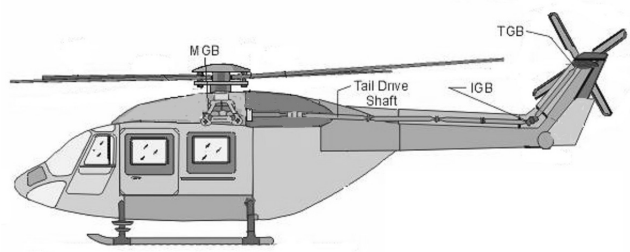

Fig.1 Arrangement of helicopter transmission

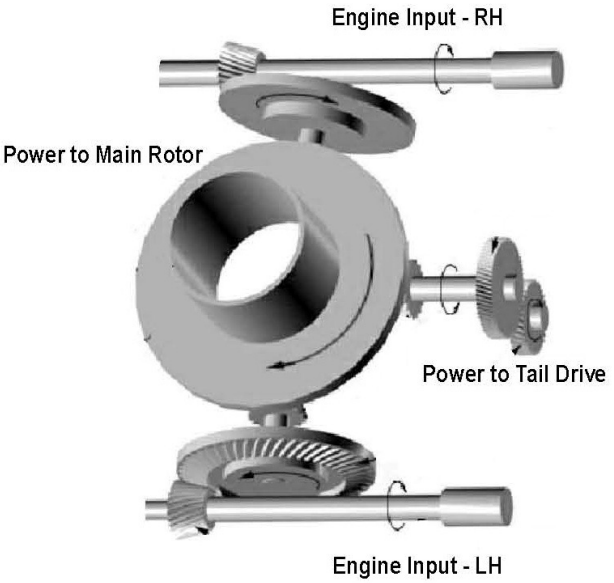

Fig.2 Typical drive train for twin engine helicopter

3. Helicopter Transmission Power Ratings

Before the test requirements are discussed, a look into different power ratings involved with helicopter operation is deemed useful.

3.1 All Engine Operative Ratings

These all engine operative (AEO) ratings include Maximum Continuous Power (MCP) for unlimited duration and higher Take Off Power (TOP) which can be utilized during take-off or landing when higher power is necessary [8].

3.2 One Engine Inoperative (OEI) Ratings

One engine inoperative (OEI) ratings are applicable to multi engine helicopters only. The ratings are 30 minute OEI Rating, Continuous OEI Rating, a higher 2 minute / 2.5 minute OEI Rating and the highest 30 second OEI Rating [8].

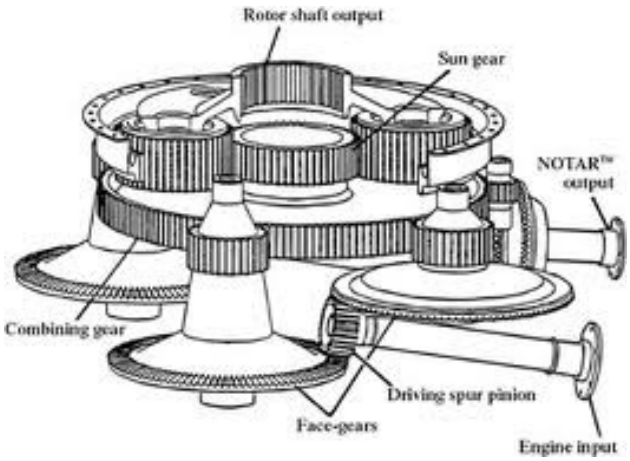

Fig.3 Typical drive train for single engine helicopter

4. Design Standards for Testing

Being a critical system of helicopter, transmission system warrants for stringent test requirements. Accordingly, standards have been defined by both military and civil

certification authorities. A brief introduction of military and civil standards is given below.

4.1 Military Standards

Fulfilling user requirements is crucial in design of military helicopters. Additionally, standards followed in the USA and U.K. are utilized. Leaflet 705, 705/1 and 705/2 of the U.K. Ministry of Defence Standard 00-970 [9] prescribe design requirements applicable to transmission system. Similarly, specification guide given in JSSG-2009 [10] is applicable to military helicopters designed in the USA.

4.2 Civil Standards

Civil helicopter design is governed by standards made by Federal Aviation Administration of USA and European Aviation Safety Agency of European Union. Design requirements for transmission are same in both the standards. FAR 29 [11] and CS 29 [12] are applicable to large rotorcraft, normally greater than 7,000 lb (3,182 kg) in maximum all up weight with multi engine configuration. For small rotorcraft (weight lower than 7,000 lb) FAR 27 [13] and CS 27 [14] are applicable. These helicopters have both single and multi-engine configurations.

5. Major Test Requirements

For the purpose of testing a rotor drive system (transmission) means any part necessary to transmit power from engines to rotor hub [9, 11-14]. Major system level test requirements are explained and compared in the following paragraphs.

5.1 Fatigue Test

Fatigue test of gearboxes is essential to determine safe life. For civil helicopters certified to FAR/CS 29, fatigue testing is necessary [15]. Test is done on one or more complete gearbox specimens chosen from different manufacturing batches. Demonstration of infinite gear life requires minimum 10^7 cycles. Power levels expected to be repeated under normal conditions are used for testing. Fatigue damage on gear teeth is not acceptable. Cat. A helicopters, certified under FAR/CS 27 must show fatigue test evidence [16]. For Cat. B helicopters, fatigue evaluation through analysis may be accepted provided it is validated by testing. Military standards too prescribe fatigue testing and requirements are similar [9].

5.2 Endurance Test

In endurance test operational load applications are simulated. The test is required to be carried out on a tied down rotorcraft. As per FAR/CS 29, test cycle of 10 hours is to be repeated for 20 cycles, resulting in a total of 200 hours testing. A typical 10 hour cycle reflecting torque levels and duration is shown in Fig.4 [15].

As per Fig.4 a single test cycle consists of seven different stages which is further elaborated in Table 3. It is noteworthy that the gearboxes are run at maximum speeds possible with the corresponding torques for stages 1, 2, 3 and 6. Minimum possible speeds are applied for stages 4 and 5. The final stage requires the test to run at maximum power on overspeed expected in service. During the second stage, rotor controls are operated to extremes in each direction for at least 15 times per hour. Controls in each position are hold for a minimum of 10 seconds. During all other cycles, controls are hold in different extremes as per Table 4.

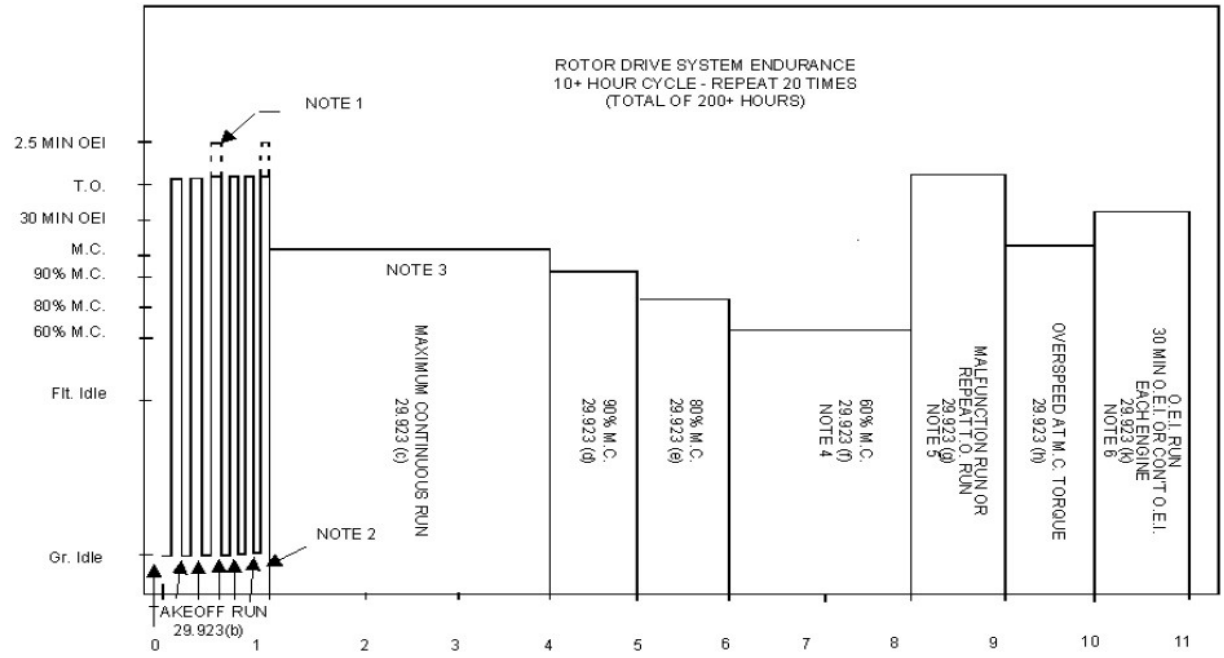

Fig.4 A single endurance test cycle

Table 3 FAR 29 endurance test details

Stg.	Ref.	Torque	Speed	Duration
1	29.923 (b)	Alternate applications of : Take off Idle	Max Min	6x5 min 6x5 min
2	29.923 (c)	Max. continuous	Max	3 hours
3	29.923 (d)	90% of Max. continuous	Max	1 hour
4	29.923 (e)	80% of Max. continuous	Min.	1 hour
5	29.923 (f)	60% of Max. continuous	Min.	2 hours
6	29.923 (g)	To repeat stage 1	Max	1 hour
7	29.923 (h)	Max. continuous	Max over speed	1 hour

Test cycle beyond 10 hours is required to cater to the OEI power ratings. Last block of Fig.1 shows extension for 30 minute or continuous OEI rating. For 30 minute OEI, extension of 1 hour (30 min each engine) and for continuous OEI, a total of 2 hours (1 hour each engine) extension of cycle is prescribed. In both cases each engine is turned inoperative alternatively and the remaining engine power is hiked up to the applicable torque level and operated for 30 minutes or 1 hour, as applicable.

Table 4 Control positions during endurance test

Control Position	Duration
Full vertical thrust	20% of the time
Forward thrust component	50% of the time
Left thrust component	10% of the time
Right thrust component	10% of the time
Aft thrust component	10% of the time

All modern helicopters also utilize 2.5 minute OEI rating or a combination of 2 minute and 30 second OEI ratings. Essential additions in test cycle are shown in Fig. 5 and Fig. 6 respectively. To qualify these ratings, stage 1 of the test cycle needs to be modified. The third and sixth runs of this stage are manipulated to accommodate OEI ratings of both engines in turn.

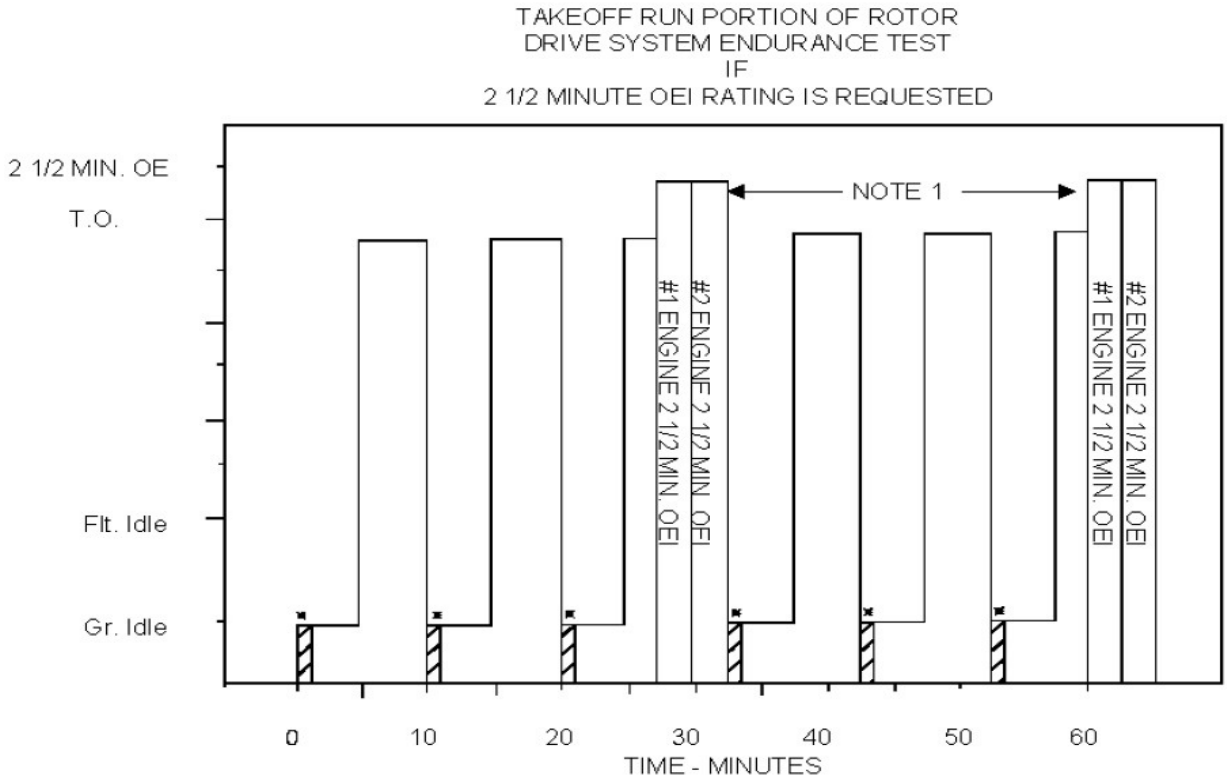

Fig.5 Introduction to 2.5 minute OEI rating

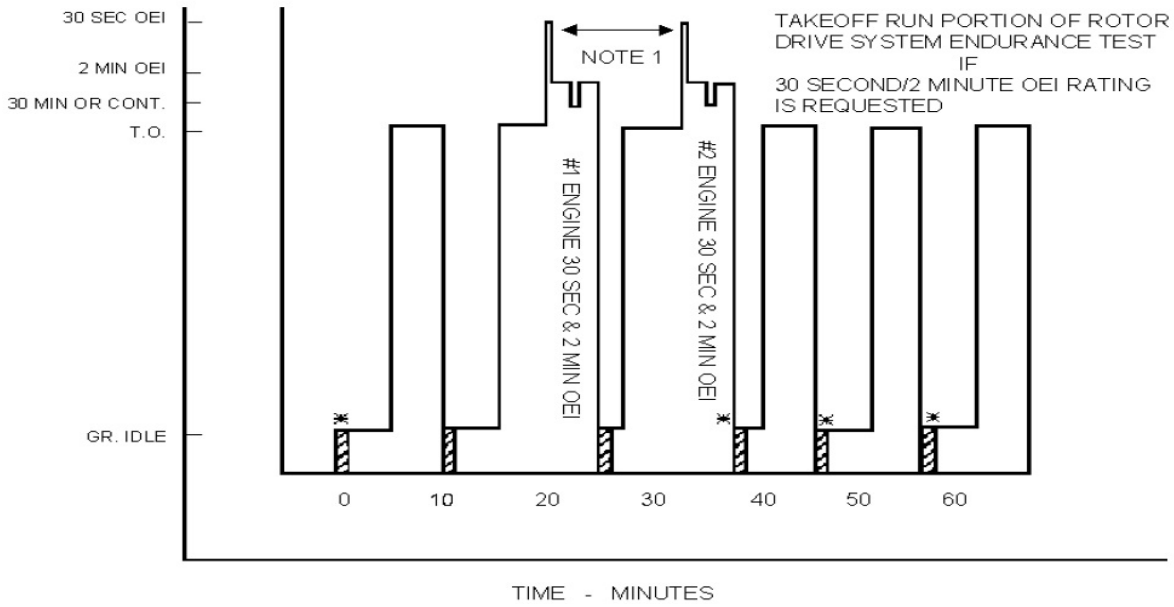

Fig.6 Introduction to 2 min. and 30 sec. OEI

In summary, for a large helicopter with continuous, 2 minute and 30 second OEI ratings, a single cycle duration is minimum 12 hours 9 minutes and total endurance test duration stands at 243 hours. Testing of 30 second OEI rating is permitted in test rig if it engine limitation warrants so. A typical test rig may be like Fig.7.

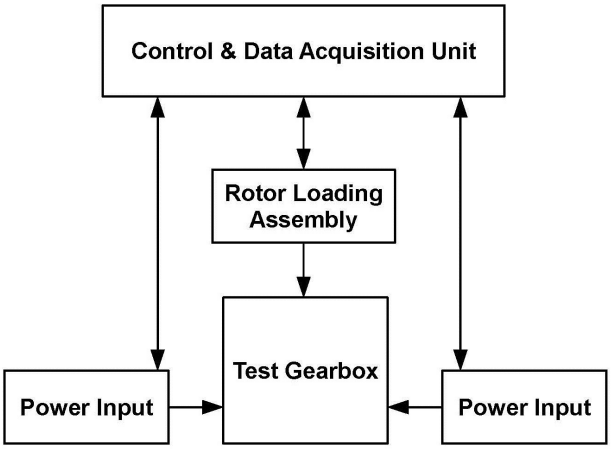

Fig.7 Schematic diagram of a transmission test rig

FAR/CS 27 prescribes a simpler endurance test of 100 hours. Test requirements are summarized below:

Unlike civil standards, military standards do not define separate test requirements for different classes of helicopters. Defence Standard 00-970 leaflet 705/2 refers to military standard MIL-T-8679 [17] for load spectrum. The test spectrum is same as Fig.4 minus OEI ratings. Addition of OEI ratings in the test spectrum is mandated in leaflet 705/2, although no specific sequence of such load application is given. This standard requires 150 hours of testing for single engine rotorcraft and 200 hours for multi-engine rotorcraft. JSSG 2009 requirement is also a 200 hours test using a "missionized test cycle that simulates projected use of the air vehicle".

None of the standards allow intervening disassembly till completion of test. Components must be in serviceable condition after the test. Defence standard does not permit disassembly after ground testing. The same gearbox is flight tested for 150 hours or 100 hours depending on twin or single engine configuration [9].

Table 5 FAR 27 endurance test details

	Ref.	Torque	Speed	Duration
FAR 27 (multi engine)	27.923(c)	Max. continuous	Max. speed	60 hours
	27.923(d)	75% Max. continuous	Min. speed	25 hours
	27.923(e)	>= take off (including 2½ or 2 min and 30 s OEI ratings)	Max. speed	10 hours
	27.923(j)	30 min OEI	Max. speed	5x30 min 5x30 min
	27.923(k)	Continuous OEI	Max. speed	5x1 hour 5x1 hour
FAR 27 (single engine)	27.923(c)	Max. continuous	Max. speed	60 hours
	27.923(d)	75% Max. continuous	Min. speed	25 hours
	27.923(e)	>= take off	Max. speed	10 hours

5.3 Dry Run Test

There have been instances when catastrophic accidents occurred due to failure of gearbox lubrication in flight resulting

in seizure of gearbox. To mitigate the hazard, demonstration of dry run capability by means of testing is required. This requirement is prescribed by all the standards mentioned in this paper. Testing is permitted in a test rig. After completion of the test, gearbox is dismantled and inspected at component level. The components need not be in serviceable condition.

Test duration and load spectrum for dry run test as per different standards are briefed below in Table 6 and Table 7 respectively.

Table 6 Dry run test requirements

	Ref.	No. of Specimens	Duration of Test (min)
FAR 29 Cat A	29.927 (c)(1)	1	30
FAR 29 Cat B	29.927 (c)(2)	1	15
FAR 27	27.927 (c)	1	15
Def Stan	705 para 3.9	1	30
JSSG 2009	4.4.11.8	2	30

The civil standards currently allow analysis as an alternate to dry run test if possibility of lubrication system failure is shown to be extremely remote. However, fatal accident of a helicopter due to lubrication loss in 2009 has warranted review of this approach. The investigation committee, in its report [18] has recommended removal of the alternate means. Additionally, it has also recommended that test duration may be reviewed for increasing it beyond 30 minutes. Such increment is perhaps need of the hour, owing to longer continued OEI operations being taken up by modern helicopters, especially to and from offshore oil rigs.

Table 7 Dry run test conditions and durations

	Power Level Simulation	Duration (min)
FAR 29 Cat A	Cruise	30
FAR 29 Cat B	Autorotation	15
FAR 27	Autorotation	15
Def Stan 00-970	Determined between designer and authority	30
JSSG 2009	Hover	2
	Cruise	26
	Vertical landing	2

5.4 Over Torque Test

Helicopter engines are sometimes more capable than gearboxes. If engine power is not limited automatically, the gearboxes would be subject to over load. To demonstrate transmission capability for withstanding higher loads during operation, FAR/CS 29 and FAR/CS 27 have introduced additional testing of gearboxes [11-14]. Test requirements are shown in Fig. 8:

The test is required to be conducted in a Ground Test Vehicle. Alternatively, use of test rig is acceptable provided it closely simulates rotorcraft vibration and torque absorption. Disassembly and passing criteria are same as endurance test.

Def stan leaflet 705/2 prescribes additional test to demonstrate the torque limiting device. Details of test, however, are not given in the standard. The same is to be agreed between the design and certification authority.

Table 8 Over torque test requirements

Ref.	Troque	Duration
27.927 (b)(1) 29.927 (b)(1)	1.1 times max. AEO torque used in endurance test	200x10 seconds
27.927 (b)(2) 29.927 (b)(2)	Max. OEI torque attainable	15 min (RHS) 15 min (LHS)

As part of integrity bench test prescribed by JSSG 2009, 100 hours test at 120% over power is required and it should be predominantly achieved by using torque above rated one.

5.5 Over Speed Test

50 over speed runs as per the following table are prescribed by FAR/CS 29. Test platform, disassembly and passing criteria are same as endurance test. No such test is prescribed in FAR/CS 27.

Def stan prescribes additional test to demonstrate containment of fractured parts. Details of test, however, are not given in the standard. The same is to be agreed between the design and certification authority.

Some part of 100 hours test at 120% power prescribed by JSSG 2009, over power is required to be achieved by over speed condition.

Table 9 Over speed test requirements

Ref.	Speed	Duration
29.927 (d)(1)	60-80% of max continuous speed	1-5 min
29.927 (d)(2)	Higher of speed due to engine control failure or 105% of max rotational speed	30±3 sec

6. Conclusions

Major ground tests applicable to helicopter transmission system have been discussed in this paper. Both civil and military requirements have been explained. Following are the highlights:

- Fatigue test requirements are similar in all standards.
- Endurance test duration is same for all standards except for FAR/CS 27.
- Def stan 00-970 appears to be more stringent, since the gearbox, on completion of 200 hours of ground test again undergoes flight test.
- FAR/CS 27 and 29 have well defined requirements for over torque and over speed tests.
- Requiring 2 dry run tests, JSSG 2009 is most stringent.
- Mandating dry run and increasing duration of test for civil helicopters have been recommended.

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