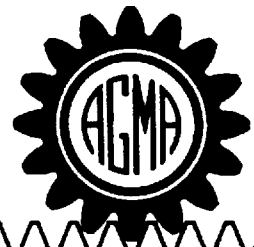


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Allowable Surface Compressive Stresses of Gear Teeth Made of Cast Iron, Tempered Carbon Steels and Tempered Alloy Steels

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TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

ABSTRACT:

Load endurance tests have been conducted to obtain allowable surface compressive stresses for materials required for strength and high reliability of power gears. The following JIS materials were used in conducting the tests: spheric graphite cast iron, G5502; carbon steel, G4051 and steel G4502. Using a designed gear with module 4 and 20 degree pressure angle as a prototype, load endurance tests were conducted, and data concerning tooth damage was accumulated. The results of these tests and comparison of the durability of the materials are presented in this paper.

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Introduction

It has been known for long time that clutching surfaces of gear teeth made of steel are damaged by the occurrence of so-called "pitting" when the gear is operated under load for certain period, and the occurrence of "pitting" would occasionally bring about the breakages of not only the gear teeth but also the whole system with the increase of vibration noise if operation of the gear is continued under the same conditions.

Occurrence of "pitting" phenomena are also observed in other mechanical elements than gears, in rolling bearings for instance.

Predominant opinion on the cause of "pitting" phenomena basing on the results of researches made for prolonged period is that they are due to the surface fatigue of the materials.

Although classifications and causes of "pitting" phenomena are not discussed in this presentation, "pitting" have been the most serious problem among the damages to be observed on gear teeth surfaces down to the present time.

It has been revealed by the recent research work that the occurrence of pitting phenomena was closely related to lubrication.

In this connection, one started to have another look at the pitting phenomena, especially from the view point of elastic fluid lubrication.

Therefore, it has been urged to change the notion of the durability of tooth surface

against pitting, that is, the calculation method of the intensity of gear tooth.

However, calculated Hertz stress on pitch circle is frequently compared with the stress of the material in order to derive the equation for determining the intensity of the teeth surfaces of gear.

Standing on this view point, it should be necessary to obtain the allowable stress of gear teeth surfaces made of various materials beforehand, as in the case of obtaining the bending strength.

For this purpose, two test methods, the roller test using cylindrical specimens and the test operating a pair of actual gear under load, have been applied for long time.

Results obtained by these tests have been adopted as the designing standards.

However, it is almost impossible to let the contacting conditions of rollers coincide with those of the tooth surfaces of gears.

Therefore, it is theoretically impossible to expect the agreements of the test results obtained by those two test methods respectively since there are several other additional differences between the two in respect to dimensional effects, temperature effects, etc.

In this connection, it is considered that test results obtained by the gear test should preferably be adopted as the precise designing standard, although those obtained by the roller test may be taken as reference only in case there is no other data available.

Due to the above reasons, tests using actual gears were exclusively carried out in this experimental program for obtaining allowable stresses of gear teeth surfaces.

Finally, test results obtained by this experimental program were compared with the experimental data which has been presented and with the specification limits which had been referred to.

1. Running Test

1.1 Test Equipment

A recirculation power type gear testing device was built as a trial. Its profile and specifications are shown in Fig.1 and Table 1 respectively.

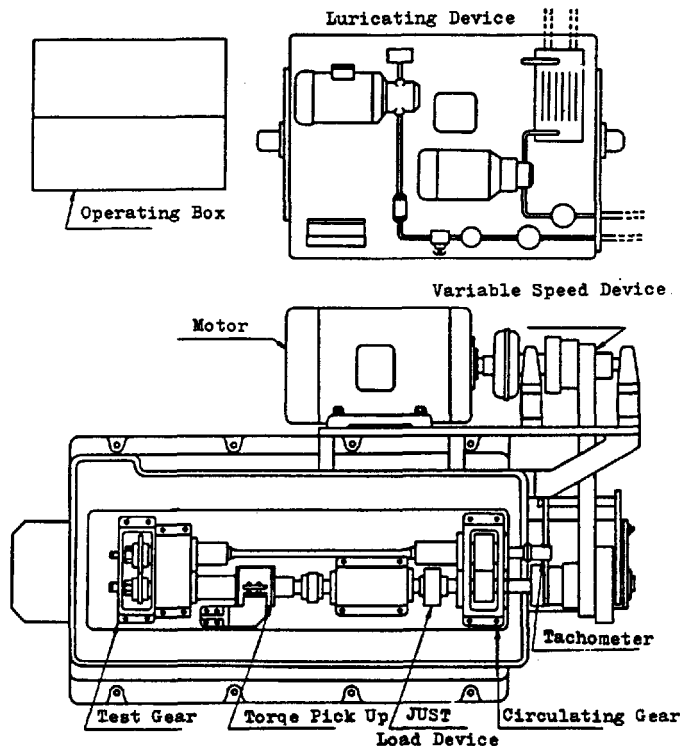


Fig. 1

Table 1

Recirculation power type gear tester

Bearing Distance : 100 mm

Circular Gear : M4, b60, Z21, 29 Spur gear. P. A 20deg.

Max. Trans. Power : 280PS (205KW)

Max. Trans. Torque : 50 Kgf-m (490Nm)/pinion

Max. Tang. driv. force : 1190Kgf (11670N)

RPM/pinion : 100, 1000, 2000, 3000, 4000

Max. Pitch-line velocity : 17.6m/s

Motor : 22KW

Apply load method : Applying harmonic driving mechanism (Just 40)

Appearance of this tester is shown in the photographs in Fig.2.

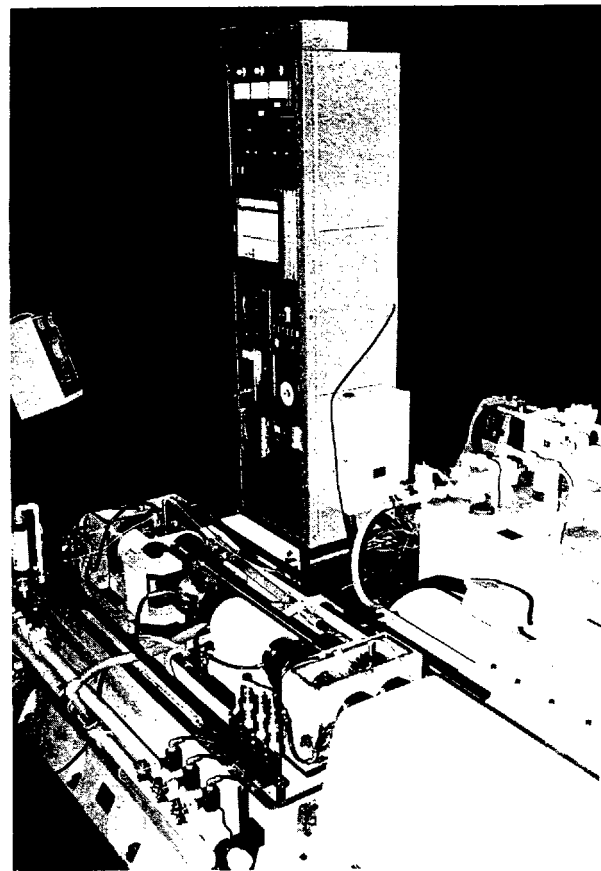


Fig. 2

The characteristics of this tester are the adoptions of stepless phase adjustable coupling applying harmonic driving mechanism being marketed under the trade name of "Just 40" as loading device and the torque pick-up applying pneumatic signal transmission device (slippingless) as torque measurement device.

By setting these devices in the axis of the circulating system, twisting load can be applied even while the tester is at rest.

Both ends of the test gear are supported by bearings. Needle bearings are used for the

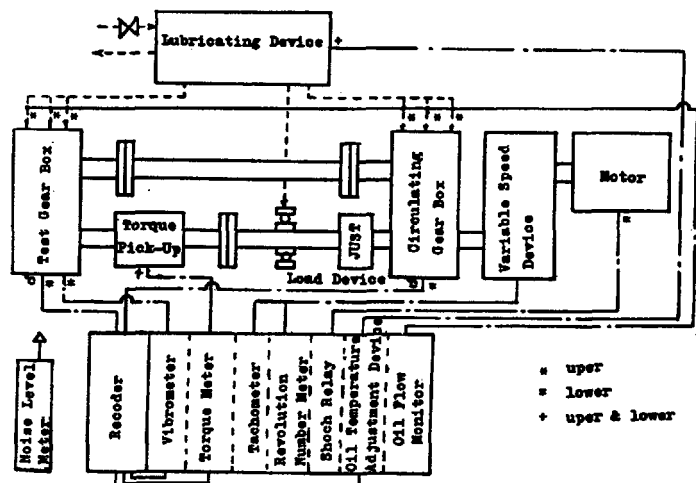


Fig. 3

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outer ends of the gear box and roller bearings are mainly used for the others.

Both gear and bearings are lubricated by the same lubricating oil forcibly fed from the same reservoir.

The oil temperature can be controlled at any temperatures within the range of oil temperature to 80°C in the accuracy of $\pm 1^\circ\text{C}$.

Controlling diagram of the measurement system is shown in Fig. 3. Changes of oil temperature, torque and vibration are recorded on the recorder and rotational frequencies, flow rates of lubricant and impact loads are read on the indicators.

Upper and lower limits of operational conditions at the necessary parts of the tester can be set and the operation of the tester can automatically be discontinued in emergency including in the case of damage.

1.2 Materials and Specifications of Test Gear set

Typical gear materials selected are cast iron, carbon steel and alloy steel.

Shown in Table 2 are the chemical composition, heat treatment procedure and mechanical characteristics of each gear material.

Table 2

Materials		Mechanical properties				
		Tension test Yield strength or point Kgf/mm ²	Tensile strength Kgf/mm ²	Elongation %	Reduction of Area %	Charpy value Kgf/cm ²
K ₁	P	43.4	55.9	5.6	4.9	0.3
	G	42.5	55.1	6.2	4.2	0.4
K ₂	P	45.5	64.7	32.1	58.2	9.3
	G	46.3	62.5	32.8	58.2	10.9
K ₃	P	47.3	74.3	29.6	63.6	7.8
	G	54.8	71.5	30.9	66.5	10.1
K ₄	P	68.4	83.6	26.2	60.5	15.0
	G	55.7	81.9	27.4	63.2	7.7
K ₅	P	83.2	95.2	23.9	65.3	20.6
	G	76.0	89.2	24.8	67.3	22.5
K ₆	P	97.6	106.8	21.5	69.9	15.1
	G	98.3	108.9	22.0	61.8	14.4

P: Pinion
G: Gear

Hardness H _B	Chemical compositions (%)									Heat treatment and temperature /Hours
	c	si	Mn	p	s	cu	Cr	Ni	Mo	
217	3.53	2.94	0.5	0.081	0.014					Normalizing Tem., / 550c/hr
190	3.53	2.94	0.5	0.081	0.014					
173	0.34	0.25	0.8	0.016	0.02	0.06	0.02	0.02		Tempering 870c/40min. Air cooling
166	0.36	0.23	0.67	0.021	0.023	0.01	0.01	0.02		
207	0.46	0.27	0.76	0.028	0.013	0.02	0.13	0.01		Primary quenching 840c /40min.Oil bass.
201	0.45	0.27	0.79	0.026	0.022	0.01	0.12	0.02		
238	0.54	0.3	0.74	0.02	0.017	0.02	0.13	0.02		Tempering 680c/2hr W.C Primary quenching 820c /40min.Oil bass.
229	0.55	0.23	0.76	0.024	0.014	0.01	0.02	0.02		
285	0.34	0.24	0.72	0.025	0.014	0.01	1.06	0.03	0.15	Primary quenching 850c /40min.Oil bass.
266	0.36	0.25	0.7	0.012	0.006	0.06	0.96	0.06	0.17	
316	0.4	0.26	0.8	0.016	0.029	0.12	1.02	0.07	0.21	Tempering 590c/2hr W.C Primary Quenching 850c /40min.Oil bass.
316	0.42	0.26	0.81	0.016	0.021	0.13	1.08	0.01	0.20	

These tables represent the combination of test gears, pinion and gear, made of six different materials respectively. Since each material for making test gears was taken from the same bar lot, the material characteristics of gear combinations made of same material, which were used for successive tests were regarded identical. Hardness of gear surface and gear core are also included in this table.

Although the hardness unit of H_B was applied as standard at the stage of design, the actual hardness was measured by applying the unit of H_V as can be seen in the table.

The hardness measurement of each gear tooth were made at five locations all one can, as per shown in Fig. 4 and shown in Table 3.

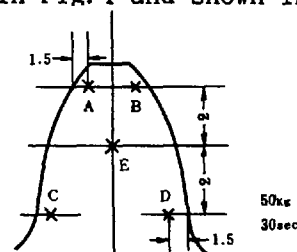


Fig. 4

Table 3

Hardness of gear surface (H_V)

Points Gear		A	B	C	D	E
K ₁	P	173.7	175.3			179.8
	G	186	190	193.5	190	189.5
K ₂	P	160	157.3			159.7
	G	147.5	150.5	155.5	155	151.5
K ₃	P	216.7	216.2			213.5
	G	213.5	215	214.5	215.5	215
K ₄	P	252.7	253			254
	G	235.5	234.5	232	237	236
K ₅	P	277	277.7			274.7
	G	281	281	276	276	279.5
K ₆	P	309.2	311.5			313.3
	G	327	334.5	324	329.5	329

Metallographs of each gear material are shown in Fig. 5. Spheroidizing phenomenon of cast iron and normal refining phenomena of carbon steel and alloy steel are clearly shown in those photographs. Test gears were manufactured by using the above materials basing on the specification shown in Table 4 and in the form shown in Fig. 6. Although it was intended to make normal profile modification on each gear profile the actual profile error curves of the finished gear teeth according to Fig. 7 and Table 4 were obtained as shown in Fig. 8. Errors observed on teeth surfaces of gears made by using the above materials and by basing on the