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FUJI ZF-TYPE ELECTROMAGNETIC TOOTHED CLUTCH

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I. INTRODUCTION

The electromagnetic clutch is employed widely in machine tools, industrial machines and more recently, in digital machine tools which are now gaining in popularity. This is due to the fact that remote control is generally easier with the electromagnetic clutch and highly efficient automation can be achieved.

The electromagnetic clutch was manufactured by Fuji Electric with technical assistance from Zahnradfabrik Friedrichshafen of West Germany. In addition to the Fuji ZF-Type EK Electromagnetic Multiple-disk Clutch (wet type), the Fuji ZF-Type EK Electromagnetic Toothed Clutch is now available.

The toothed clutch can be engaged only in the stationary state or when the relative rotational speed is low. The clutch is small compared to the multiple-disk clutch. The transmission torque is large but, when the clutch is released, no torque is transmitted to the load. Another feature is that there is no frictional heat produced during operation. To select the type most suited to the application, it is necessary to sufficiently understand these special features and clutch performance. An outline of the EK electromagnetic toothed clutch will be given below.

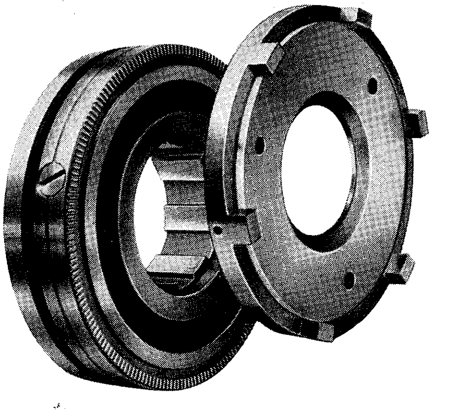


Fig. 1 View of EK electromagnetic toothed clutch (Basic type)

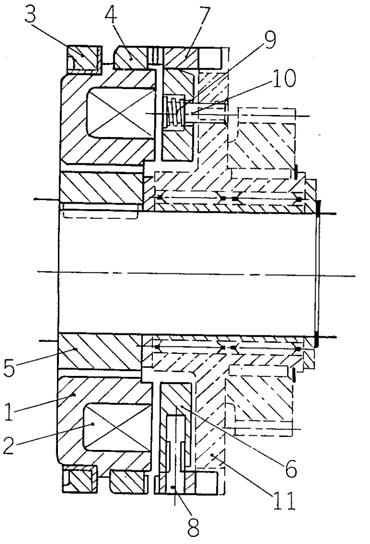


Fig. 2 Construction of EK toothed clutch

II. CONSTRUCTION AND DIMENSIONS

1. EK Electromagnetic Toothed Clutch (Basic type)

The EK electromagnetic toothed clutch (basic type) is of the rotary coil type. *Fig. 1* shows an external view of the clutch and *Fig. 2* is a sectional construction diagram. In accordance with *Fig. 2* coil (2) is molded into magnet body (1). Slip ring (3) is shrink-fitted and toothed ring (4) is fixed to the magnet body. Spline grooves are machined on the inside of the magnetic body which is then fixed to the spline drive shaft directly or with a suitable spline bushing (5).

Armature (6) and toothed ring (7) are connected with spring rod (8). Projections of the toothed ring engage the grooves of armature holder (11) of the driven-side unit, transmitting torque in the rotating direction. The driven-side unit can slide freely in the shaft direction. In addition, return spring (9) is compressed by bolt (10) in the armature. The bolts must be screwed tightly to the armature holder.

When the coil is energized via the brush and slip ring, the armature is attracted to the magnet body against the spring tension. When the toothed rings engage with each other, the drive- and driven-side units are connected. When the coil is deenergized, the armature is quickly retracted with the aid of the spring rod and return spring so as to release the engagement.

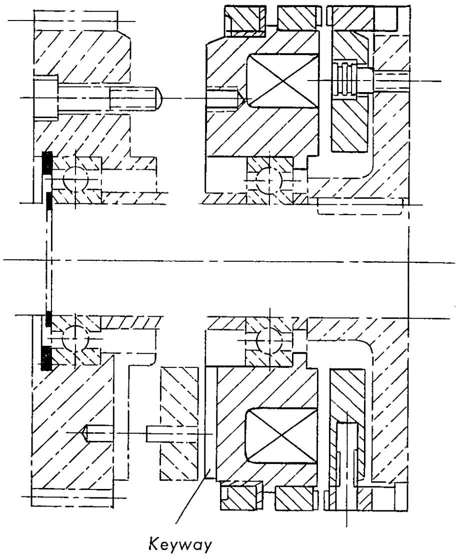


Fig. 3 Construction of EK toothed clutch (B type)

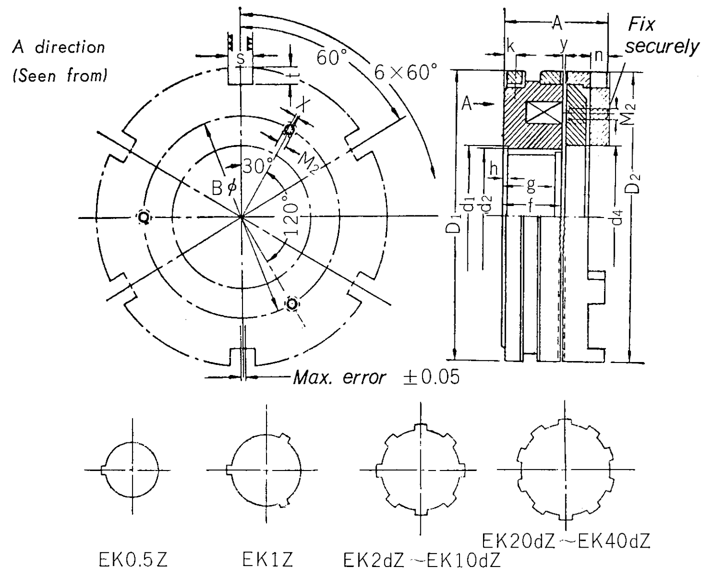


Fig. 4 Outline of EK type toothed clutch (Basic type)

2. EK Electromagnetic Toothed Clutch (B type)

Contsruction of the EK electromagnetic toothed clutch (B type) is shown in *Fig. 3*. Drive power is transmitted through the keyway on the rear surface of the magnet body which is supported by bearings on the shaft.

Unlike the basic type, the armature is fixed to the shaft by an armature holder.

The external dimensions of the basic type and B type toothed clutch are indicated in *Figs. 4* and *5* respectively, with the values for the various types given in *Table 1*.

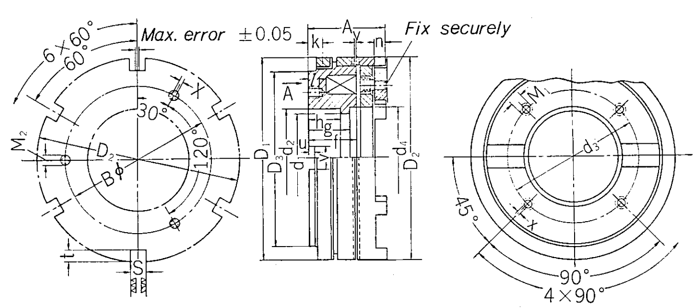


Fig. 5 Outline of EK type toothed clutch (B type)

Table 1 **Dimensions of EK Type Toothed Clutch (Basic and B Type)**

Clutch Type	Transmission Torque (kg-m)	Dimensions (mm) *1) A	$D_1=D_2$	D_3	d_1	*2) d_2	d_3	M_1	d_4 +0.2	M_2	$B\phi$ ±0.1	f	g	*3) h	k	l	n	S +0.1 +0.05	t	u +0.1	v H7
EK 0.5 Z	2	27.5	70		27	key way 6×1.5 25	—	—	26	M3	45	17	17	1.5	3.5	—	4	7	5	—	—
EK 1 Z EK 1 BZ	5	37 39	82	— 67	36 31	34 key way 6×1.7 35	— 50	— M5	35	M4	55	23 25	23 22.5	1.5 20	5.5 7.5	— 5	6	8	5.5	— 2.5	— 12
EK 2 dZ EK 2 dBZ	10	38 40	95	— 78	42 37	8×36×40 42	— 56	— M6	45	M4	65	23 25	20 22	1.5 20	5.5 7.5	— 5	6	8	6	— 2.5	— 12
EK 5 dZ EK 5 dBZ	25	43 47	114	— 95	52 45	8×46×50 55	— 75	— M8	53	M4	80	26 30	23 25	2 22	6 11	— 7	7	10	8	— 5	— 14
EK 10 dZ EK 10eBZ	50	50 54	134 140	— 120	60	8×52×58 68	— 90	— M8	63 70	M5	100	29 33	26 28	2 22	7 11	— 8	8	10	8	— 5	— 16
EK 20 dZ EK 20 dBZ	100	60	166	— 142	80 65	10×72×78 75	— 100	— M10	80	M6	120	35	30	2.5 25	7 13	— 9	9.5	12	11	— 6	— 20
EK 40 dZ EK 40 dBZ	200	68 68.5	195	— 170	90 80	10×82×88 90	— 116	— M10	89	M6	150	38.5 39	33.5 34	3 28	7 13	— 12	12	15	12	— 6	— 20

Note: *1) Dimensions when clutch is released

*2) Z type: EK 0.5→EK 1 Z keyway ϕH 7

EK 2 dZ and above Spline grooves conform to JIS B 1601 Type 1

BZ type: Hole diameter ϕK 6

*3) Z type: +0.05, BZ type +0.2

X: ±0.1 Y: EK 0.5Z→EK 1 BZ $0.3^{+0.2}$, EK 2 dZ and above $0.4^{+0.3}$

III. FEATURES

1) Transmission torque is large

Unlike so-called friction clutches such as the electromagnetic multiple-disk and single-disk clutches, the toothed clutch transmits the torque via a mutual engaging of teeth. The transmission torque therefore is very large compared with a friction clutch of the same external dimensions. Transmission is also reliable and accurate.

2) Small and lightweight

Since this is a rotary coil type clutch, construction is very simple and the unit is very small and lightweight. Dimensions in the shaft direction especially are small, facilitating application in locations where space must be economized.

3) No torque is transmitted when the clutch is released.

When the clutch rotates in the deenergized state, the toothed rings are completely disengaged and no torque is transmitted to drive the load. Therefore, there is no need to worry about heat generation in the deenergized state.

4) Quick operation

Usually, the gap between the magnet body and the armature is narrower than that in the friction type. Engage time, therefore, is shorter, and the unique armature construction also insures a short release time.

5) Both wet and dry types can be used

Generally, the wet type is preferred but the dry type is possible simply by replacing the brushes.

IV. CHARACTERISTICS

1. Transmission Torque

The transmission torque of the toothed clutch can be expressed approximately by the formula

$$T = PR_m \tan(\alpha + \rho) \quad \text{..............} \quad (1)$$

where

T: Transmission torque (kg-m)

P: Difference between electromagnetic engage force and return spring force (kg)

R_m: Mean radius of the engaging teeth(m)

α: Angle of tooth wall (acute angle between the bottom surface and the side surface of a trapezoidal tooth) (degree)

ρ: Friction angle of tooth wall (degree) where friction coefficient $\mu = \tan\rho$.

It is evident from formula (1) that, with the same shape and dimensions, the transmission torque is proportional to the difference between electromagnetic engage force and return spring force. Therefore, return spring force must be small to obtain a large transmission torque. However, if return spring force is small, the release time becomes longer and thus a compromise must be reached between transmission torque and release time.

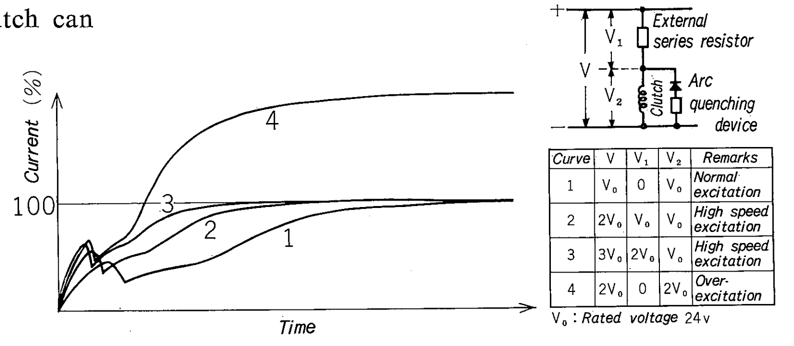
This problem has been overcome in the toothed clutch by the unique armature construction and both a short release time and a small engage force are obtained. The trapezoidal tooth is adopted as standard because it allows easy engaging during rotation. It has also been confirmed that there is almost no difference in torque when a wet type or dry type clutch is used.

The transmission torque increases more slowly than the energizing current, and transmission torque is therefore guaranteed at energizing current i_{120} (current value at rated voltage assuming that the coil temperature has reached the maximum value of 120°C.)

2. Engage Time

The engage time of the toothed clutch is the time which elapses from the instant the coil is energized to the instant contact is made with the armature. The current rises according to the coil time constant. Characteristics of each type are shown in *Table 2*.

There are two methods of reducing the engage time further. In the high-speed excitation method, the time constant is reduced by inserting a series resistor in the coil circuit of the toothed clutch, while in the over-excitation method, the coil is excited by a voltage greater than the rated voltage. *Fig. 6* shows an example of the two methods. In the high-speed excitation method, the inserted resistor is most effective when it is 3～4 times the coil resistance. In the over-excitation method, it is necessary to reduce the voltage to the rated value after the toothed clutch is engaged.



Curve	V	V_1	V_2	Remarks
1	V_0	0	V_0	Normal excitation
2	$2V_0$	V_0	V_0	High speed excitation
3	$3V_0$	$2V_0$	V_0	High speed excitation
4	$2V_0$	0	$2V_0$	Over-excitation

V_0 : *Rated voltage* 24 v

Fig. 6 Current vs. time at over-excitation

3. Release Time

The release time of the toothed clutch is the time which elapses from the instant the coil is deenergized to the instant the toothed rings are released. The release time depends on the following factors.

1) Residual magnetism of the magnetic circuit and the oil film on the pole surface.
2) Return spring force
3) Electrical time constant
4) Friction of the sliding section of the armature

Residual magnetism can be decreased by leaving a gap between the magnet body and the pole surface of the armature in the engaged state. A shorter release time can be obtained by increasing the return spring force but this increase is limited by the relation in formula (1) and by the value of the electromagnetic engage force. The armature and the toothed ring on the armature side are connected with a special spring rod. As shown in *Fig. 7,* the armature is attracted to gap S_1 against the return spring force. At the gap of S_1, the toothed rings are completely engaged and the armature is attracted from S_1 to S_0 against the force of both the return spring and the special spring rod to complete the engagement.

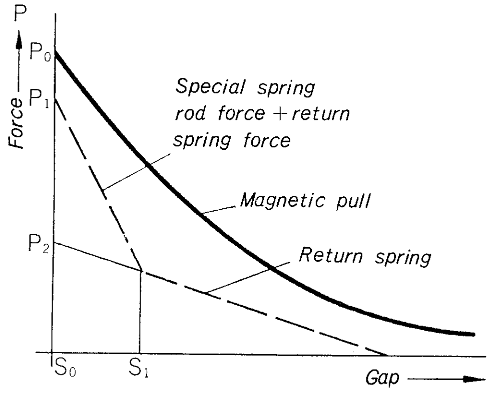


Fig. 7 **Magnet pull and spring force**

When the coil is deenergized, the armature overcomes the adhesive force of the oil and slight pulling force due to residual magnetism and is accelerated by the forces of the special spring rod and the return spring so as to give a short release time. In addition, the engage force on which the transmission torque depends becomes P_0–P_2 and measures are taken so that the force P_1–P_2 of the special spring rod does not influence transmission torque.

Table 2 **Example for Characteristics of EK Type Toothed Clutch**

Clutch Type	Transmission Torque (kg-m)	Voltage dc (V)	*1) Power Consumption (w)		Response Time (ms)		Flywheel Effect (kg-m²)	
			P_{20}	P_{120}	Engage t_1	Release t_2	Magnet body side	Armature side
EK 0.5 Z	2	24	12	8.5	20	50	0.0012	0.0004
EK 1 Z	5	24	13	9.5	25	50	0.0028	0.001
EK 2d Z	10	24	28	20	30	60	0.0051	0.0019
EK 5 dZ	25	24	48	35	30	80	0.0112	0.0045
EK 10 dZ	50	24	57	41	40	105	0.0243	0.0099
EK 20 dZ	100	24	68	49	65	115	0.0650	0.0240
EK 40 dZ	200	24	79	57	75	190	0.1434	0.0616

Note: *1) Wattage after the coil temperature has reached 20°C and 120°C respectively.

To compensate for factors 3) and 4), a varistor is employed in the circuit. Efforts have also been made to improve the release time by means of precise finishing and machining of the sliding section of the armature. (Refer to *Table 2*)

V. SELECTION AND OPERATIONAL PRECAUTIONS

Although the toothed clutch has the special features described earlier, application is subject to the following limitations. Since torque is transmitted through the teeth, the clutch can be released at any rotational speed or load. However, coupling of the clutch is possible only in the stationary state or when the relative rotational speed is small. The toothed clutch is assembled in the machine as a unit and therefore there are limitations in its dimensions. Since it is difficult to modify or replace the clutch care must be taken in selecting the most suitable model. Since unlike in the multiple-disk clutch torque transmission is by engaging teeth, the toothed clutch must not be operated with the teeth overlatched. Therefore, it is extremely important to consider the torque requirements and engaging conditions when selecting the type of clutch to be used.

1. Engaging in the Stationary State

With the application shown in *Fig. 8*, care must be taken to insure that the motor does not start before the toothed clutch is engaged. When engaging in the stationary state, the teeth either completely engage or make top-to-top contact without engaging.

1) Case when the teeth engage

When the toothed clutch is installed as in *Fig. 8* and the motor is started after engaging the teeth, the torque T applied to the toothed clutch can be expressed by the following formula.

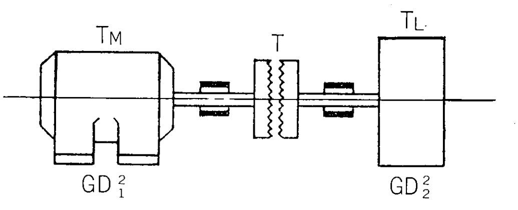


Fig. 8 **Equivalent illustration of toothed clutch**

$$T=(T_M-T_L)\frac{GD_2^2}{GD_1^2+GD_2^2}+T_L \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where GD_1^2: Flywheel effect of driving side (kg-m²)
GD_2^2: Flywheel effect of driven side (kg-m²)
T_M: Maximum torque of driving side (kg-m)
T_L: Load torque of driven side (kg-m)
T: Torque applied to toothed clutch when starting (kg-m)

Therefore, it is necessary to select a toothed clutch which has a transmission torque larger than T of formula (2). When the load torque is applied after high speed has been reached as in most machine tools, the transmission torque of the toothed clutch must always be higher than the load torque used. Because of the difficulties in making a correct estimation of the load torque, torque characteristic of the motor, GD^2, etc. or the methed of applying the clutch load, it is necessary to select a clutch with sufficient safety margins. Otherwise, the clutch may slip and be unable to accept the load. The easiest way, without going through detailed calculations, is to select a toothed clutch which has a transmission torque larger than the maximum motor torque (generally, about 400% of the rated motor torque), in which case there is no problem when the motor is rotated is one direction only.

2) Case when the teeth are in contact but not engaging

When the motor is started with the toothed clutch coupled in this state, the engaging process which follows will differ according to torque characteristics of the motor, GD^2 of the entire system, load torque and rotational speed of the toothed clutch shaft. The process is not electrically or mechanically static but dynamic. Since the calculations are complicated, an approximation can be made from experimental results using static calculations.

Fig. 9 shows an example of decrease in the permissible torque against the rotational speed of the toothed clutch shaft when the motor is started after the clutch is coupled in the stationary state without the teeth engaging. This relation differs according to motor torque characteristics but generally, the smaller the motor starting torque or the slower the rotational speed of the toothed clutch, the larger is the transmission torque allowed for the toothed clutch during starting. There is also an instantaneous overexcitation method which can be used to increase the permissible torque of the toothed clutch in this case. (Patent pending)

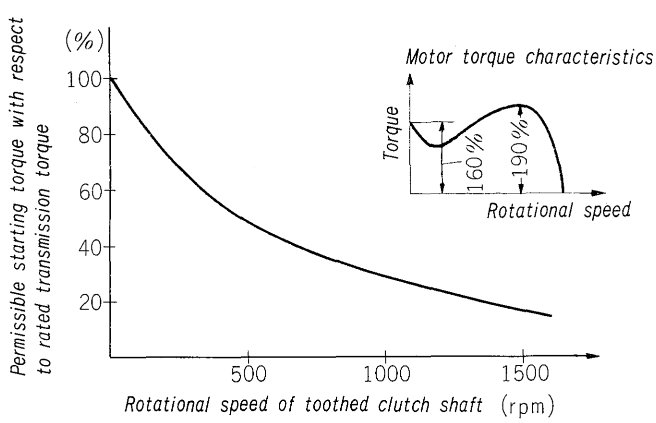


Fig. 9 Example for permissible starting torque vs. rpm on the toothed clutch engaged at standstill

2. Engaging During Rotation

As a rule, engaging is possible when the relative rotational speed is low. If there is no elasticity in the drive or driven units, engaging during mutual rotation of the two units theoretically means that mass should abruptly be accelerated instantaneously. However, in practice, engagement in this case is possible because there is always some elasticity in the drive and driven units. Therefore, with elasticity taken into consideration the permissible relative rotational speed, load torque and GD^2 differ according to the engaging conditions but they are difficult to difine.

Fig. 10 shows the approximate relation of the load due to friction and GD^2 against the permissible rotational speed. When the torque applied on the toothed clutch is large at the instant the rotating units are engaged, the permissible rotational speed is small. In actual practice engagement is not always impossible even at rotational speeds higher than 30 rpm. However, in this case, a careful study of the engaging conditions is necessary.

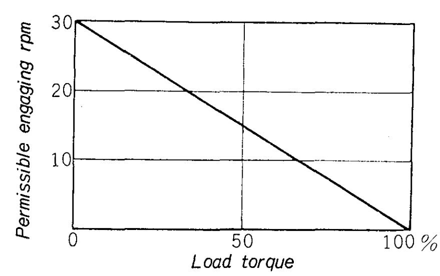


Fig. 10 Approximate relation between permissible engaging rpm and load torque

3. Other Precautions

1) The wet type and dry type of electromagnetic toothed clutch can be used but the wet type is preferred considering friction in the sliding section and rust prevention.

When using the wet type, lubrication oil has only to be supplied slightly unlike in the multiple-disk clutch, since the toothed clutch has no working loss during engagement. Any of drop-, sprash- or oil mist-lubrication is enough.

2) The brushes are screwed tightly to the gear box or to a support to avoid vibration. With the wet type brush, it is necessary to non-electrically connect a so-called idle brush in addition to the usual brush when the slip ring speed exceeds 10 m/s or when the current is applied almost continuously.

With the dry type clutch, a dry type brush is used and oil must not be applied to the slip ring surface irrespective of the speed of the slip ring.

3) During installation, the gap between the toothed rings in the deenergized state must be set within the specified range, the armature must move easily in the shaft direction and the toothed clutch axis must be properly aligned with the shaft.

VI. APPLICATION

The toothed clutch is applied widely for automation and control centralization in machines using the conventional gear shift system, in machines which engage in the stationary state or at low speeds and in machines which require accurate torque transmission and release.

Fig. 11 shows an example of a machine tool with a number of type EK toothed clutches installed in the main shaft gear shift unit. The rotational speed of the main shaft can be changed by a dial to any of the 18-speed selection values (ranging from 40 to 2200 rpm). The main spindle transmission unit is much smaller and more compact when the type EK toothed clutch is used and, the temperature rise in the unit during operation is small.

The type EK toothed clutch can be used to control lateral or forward and backward feed of milling machine tables by switching between two clutches installed in the feed gear unit. The transmission of torque to light loads during release, always a problem in wet type electromagnetic multi-plate clutches, is solved in the toothed clutch.

Very good results were obtained both in these cases and in many other applications.

VII. CONCLUSION

This paper has presented an outline of the construction, characteristic, selection, operational precautions, etc., of the Fuji ZF-type EK toothed clutch. The problem of engagement during rotation of the electromagnetic toothed clutch will be discussed in more detail in a later paper. The author hopes that this paper will be of some help to machine designers.

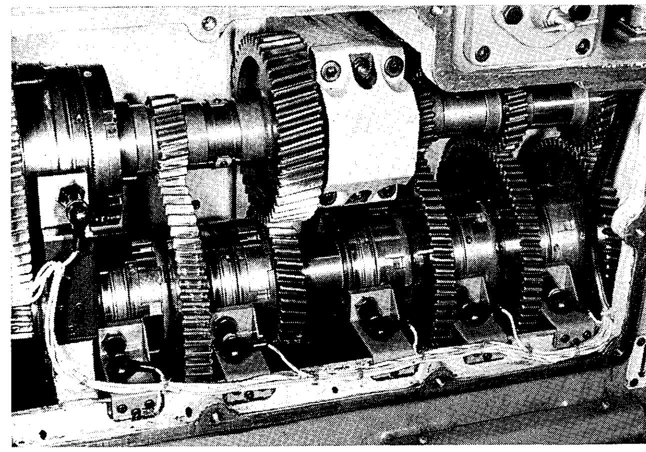


Fig. 11 View of gear trains

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