Reducer with a planetary gear train for a hoisting mechanism of dangerous goods cranes

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Abstract: In addition to the universal requirements for handling (lifting and transport) machines (HM), HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements. One of these requirements is the drive of the hoisting mechanism with two motors, to ensure in case one of them fails. The article discusses a reducer for the hoisting mechanism of an overhead crane for dangerous goods with an embedded planetary gear train, allowing both motors to operate at full power (and without overload) in both regular and emergency (in failure) mode. The different modes of work of the mechanism are considered (with both motors and with each one separately). An analysis of the possible kinematic schemes of the planetary gear train is made. The necessary kinematic calculations have been made to select the most suitable variant of the planetary gear train.

KEYWORDS: CRANES, DANGEROUS GOODS, GEAR TRAIN, HANDLING MACHINES

1. Introduction

Risk management in the transport and handling of dangerous goods has always been relevant [8]. In addition to the universal requirements for handling (lifting and transport) machines (HM) [1, 2, 5, 6], HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements [10]. Some of these requirements apply to the machine as a whole [6]. Others refer to individual mechanisms or to their aggregates and assemblies [5].

In the framework of a research project with UCTM (Univ. of Chemical Technology and Metallurgy), the authors have examined only those requirements that relate to the gear trains of the mentioned mechanisms:

1. Ensuring micro-speed of the hoisting mechanism, in accordance with the specifics of the processed dangerous goods.
2. Drive of the mechanisms with two motors, which are able to work independently in case of emergency (failure of one motor) [7]. This is especially important in metallurgical machines working with molten metal. If one motor fails, the other must be able to complete the operation so that the metal does not freeze in the bucket.

This paper examines some solutions that meet the second requirement.

Classic solution: Each of the motors (I and II) is selected with a power of 65 - 85% of the required for the drive of the mechanism, which allows independently, in overload mode, to complete the hoisting operation to the end:

\[ P_{Al} = P_{AII} = (0,65 \div 0,85) P_b \] and \( \omega_{Al} = \omega_{Al} \).

Disadvantage: In normal operation, each of the motors operates at 77 – 60% of its rated power [9], which leads to lower efficiency.

Rational solution: Gearbox with embedded planetary gear train [3, 4] – each of the motors is selected with a power of 50% of the required and in both regular and failure mode operates at 100% of its rated power:

\[ P_{AI} = P_{AII} = 0,5 P_b \] and \( \omega_{AI} = \omega_{AII} \).

The considerations here are made for a single-carrier planetary gear train of the most often used type – \( \overline{AI} \)-planetary gear train (Fig. 1), but in the process of work a variant with A1-planetary gear train is also considered (Fig. 2).

As shown in Figure 1 these gear trains have two central gear wheels – a sun gear 1 with external teeth and a ring gear 3 with internal teeth. These two gears 1 and 3 mesh with one-rim or two-rim planets 2 which are housed in carrier H. Their number most often is \( k = 3 \), rarer \( k = 2 \) or 4, but in special cases there are PGTs with \( k = 20 \) planets [PGT]. However, planets number \( k \) does not affect the gear train’s kinematics.

Fig. 1 Most often used \( \overline{AI} \)-planetary gear train with one-rim planet with one external and one internal meshing.

Fig. 2 \( \overline{AI} \) - and A1 -planetary gear trains and their basic ratio.

Central elements of the gear train (sun gear 1, ring gear 3 and carrier H) rotate around an axis – the so-called main (central) geometrical axis of the gear train. Typical of this simple PGT is that there are three shafts that go out of the train (external shafts). In Fig. 1 the corresponding external torques \( T_1 \), \( T_3 \), and \( T_H \) also are shown. Two of them \( T_1 \) and \( T_3 \) are unidirectional, and the third torque \( T_H \) is with opposite direction. Since the train is simple, of course, it has only one carrier, i.e. it is a single-carrier PGT.

These trains, like other PGTs, can operate both with \( F = 1 \) and \( F = 2 \) degrees of freedom. With \( F = 1 \) degree of freedom any one of three shafts (of the sun gear 1, ring gear 3 or carrier H) can be fixed. With a fixed carrier (\( \omega_H = 0 \)), the PGT works as pseudo-planetary. At \( F = 2 \) degrees of freedom (working as differential), six working modes are possible – three as a summation PGT and three as a division PGT.

The kinematic analysis of this gear train – the determination of speed ratios when working with \( F = 1 \) degree of freedom or speeds...
of the input shaft(s) in case of \( F = 2 \) degree of freedom is made through the basic speed ratio \( i_0 \) – the ratio of the pseudo-planetary gear train working as reducer with fixed carrier (\( \omega_H = 0 \))

\[
i_0 = i_{U(H)}
\]

The gear ratios of the other cases of work with \( F = 1 \) degree of freedom (Fig. 2 a and b) are expressed through it [3, 4]. The above possibilities are used in the mechanisms discussed in the paper.

2. Tween-motor driven hoisting mechanism – in regular mode working

Fig. 3 shows the kinematic scheme of the reducer of the main hoisting mechanism of a 190-ton overhead (bridge) crane with embedded planetary gear train. As mentioned above, for high-capacity cranes, twin-motor drive is desirable (and for foundries and dangerous goods in general, it is mandatory). It is made so that if one motor fails, the other is able to complete the necessary movement on its own. Usually, when no differential is used, the two motors drive the input shaft and select the same power and angular velocity, each with a power equal to 65 - 85% of the total required power, so that they can operate independently in failure mode, although and with overload (see formula 1).

In the shown in Fig. 3 arrangement this disadvantage is avoided due to the use of \( A1 \)-planetary gear train. Both motors are selected with the same power \( P_{AI} = P_{AII} \) (equal to 50% of the required for the hoisting mechanism) and angular velocity \( \omega_{AI} = \omega_{AII} \) and in regular mode (Fig. 3) operate at their rated power

\[
P_B = P_{AI} + P_{AII}.
\]

When both motors are working, the angular velocity \( \omega_H \) of the carrier \( H \) of the planetary gear train is determined by the known formula for summing the motions [3, 4]

\[
\omega_H = \frac{\omega_A - i_{01} \cdot \omega_{AII}}{1 - i_0} = \frac{\omega_A + t \cdot \omega_{AII}}{1 + t},
\]

where

\[
\omega_A = \omega_{AI} = \omega_{AII},
\]

\[
\omega_3 = \frac{\omega_A}{i_{45}} = \frac{z_5}{z_4}.
\]

Obviously, the directions of rotation of the sun gear and the ring gear must be the same, which means that the motor shafts must rotate in opposite directions, i.e.,

\[
\omega_{AI} = -\omega_{AII}.
\]

The angular velocity \( \omega_B \) of the output shaft \( B \) of the gearbox, resp. of the rope drum is determined by the following formula, taking into account the speed ratios of the last two stages steps

\[
\omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{i_{67} \cdot i_{89} \frac{z_6}{z_7} \frac{z_9}{z_8}}.
\]

Fig. 3 Reducer of hoisting mechanism of an overhead (bridge) crane with tween-motor drive with embedded planetary gear train.

3. Tween-motor driven hoisting mechanism – in failure mode working

3.1. Motor II is in failure

In this case only the motor I is working (Fig. 4), i.e.,

\[
P_B = P_{AI}
\]

Planetary gear train works with fixed ring gear, i.e., \( \omega_1 = \omega_{AI} \)

\( > 0 \) and \( \omega_3 = 0 \). The carrier angular velocity is [4]

\[
\omega_H = \frac{\omega_{AI}}{i_{HI(3)}} = \frac{\omega_{AI}}{i_{HI(3)}} = \frac{\omega_A}{1 + \frac{z_3}{z_1}}.
\]
i.e., lower than in case of work of both motors and this reflects to the output angular velocity

\[ \omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{z_7 \cdot z_9 / z_6 \cdot z_8} . \]

### 3.2. Motor I is in failure

In this case only the motor II is working (Fig. 5), i.e.,

\[ P_B = P_{III} \]

Planetary gear train works with fixed sun gear, i.e., \( \omega_A = \omega_{III} \) and \( \omega_I = 0 \). The carrier angular velocity is [4]

\[ \omega_H = \frac{\omega_{III}}{i_{67} \cdot i_{89}} = \frac{\omega_A}{z_7 \cdot z_9 / z_6 \cdot z_8} . \]

as \( \omega_B \) is determined by the same formula, but with different \( \omega_H \)

\[ \omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{z_7 \cdot z_9 / z_6 \cdot z_8} . \]
4. Kinematic analysis

**Aim:** Objective: to obtain the same output angular velocity $\omega_B$.

This is possible at the same angular velocity of the carrier in both cases, i.e.,

$$\omega_H = \frac{\omega_{AI}}{1 + \frac{z_3}{z_4}} = \frac{\omega_{AII}}{1 + \frac{z_4}{z_3}}.$$ 

**Solution:** Since the angular velocities of the motors are equal in magnitude (identical motors) and opposite in direction $\omega_{AI} = -\omega_{AII}$, following equation must be satisfied

$$\left(1 + \frac{z_3}{z_4}\right) = \frac{z_4}{z_3} \left(1 + \frac{z_4}{z_3}\right).$$

After processing, the ratio is obtained, which is obvious from the kinematic scheme (which maintains the same output torque $T_H$ of the planetary gear train)

$$\frac{z_3}{z_4} = \frac{z_4}{z_3}.$$ 

5. Conclusions

In compliance with the derived dependence, both motors operate at rated power $P_{AI} = P_{AII} = 0.5 P_B$ in regular operation mode $P_{AI} + P_{AII} = P_B$ and in emergency (failure) mode. In the second case, the mechanism operates at twice less power, but at twice less angular velocity, so that the torque of the drum shaft remains the same as in regular operation.

The analysis showed that when using the more complex AI-planetary gear train, a great kinematic advantage is not achieved.

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7. References

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