Some requirements to the mechanisms of handling machines for dangerous goods and solutions for their satisfaction

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Abstract: *The article reviews the requirements for the lifting mechanisms of cranes according to various regulations concerning dangerous goods. Particular attention is paid to these requirements regarding gear trains. Some design solutions for providing microspeed as well as for twin-motor drive are discussed. These arrangements are suitable for both lifting and travel mechanisms. A kinematic analysis was made and recommendations were given to the designers.*
KEYWORDS: CRANES, DANGEROUS GOODS, GEAR TRAIN, HANDLING MACHINES

1. Introduction

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. These requirements can be found in the relevant regulations, such as the regulations of the State Agency for Metrology and Technical Supervision [16, 17] and various national and international standards [1, 2, 6, 7, 8, 9, 10, 12].There are also good practices that manufacturers adhere to, even though they are not regulated [18].

Some of these requirements concern the machine as a whole (seismic resistance, elevated safety factors and requirements for the reliability of the parts, etc.). Others refer to the individual mechanisms or their units and assemblies.

BDS 8916-81 [6] stipulates that the group of working modes (duty) of load lifting mechanisms and jib lifting mechanisms for cranes transporting molten metal or slag, toxic, explosive substances and other dangerous goods must is not less than 5, except for self - propelled jib cranes, for which it must be not less than 3.

This requirement does not apply to auxiliary lifting mechanisms if they do not take part in the transport of the above loads. In the absence of specific data for determining the class of use and the load factor, it is allowed to determine the group of the operating mode from a table listing the different types of cranes and their mechanisms (main and auxiliary lifting, trolley and crane movement, rotation, range change and other mechanisms). In this table, the recommended working mode of the main lifting mechanism for most metallurgical cranes (with forks, mold, multi-magnetic, multi-grapple, for loading furnaces, stripper, shaft, clamps) is very heavy (6^{th}group), whereas for hardening, foundry (casting), and forging crane - heavy (5^{th}group).

In BDS ISO 4301-5 [9] there is no special text for cranes for dangerous goods, but in the table with instructions are assigned the highest classification groups - A7 and A8 for the crane and M7 and M8 for the mechanisms. The classification of bridge and gantry cranes and their mechanisms, depends on the use of the crane for cranes in steel mills (Table 1). Exceptions are only the cranes in the rolling mills (A2, M3, and M4 respectively).

Irrespective of the mode of operation in the strength calculation of the hoists of cranes for molten metal or slag, poisonous and explosive substances, a safety factor of not less than 6 must be used (as for very heavy-duty operation of cranes and jib cranes). Moreover BDS 15164-80 [7] obliges protection with fences of the ropes of cranes carrying molten metal or liquid slag from the direct action of heat and splashes of metal.

According to BDS 16879-88 [8] during changing the range and traveling of the cranes and trolleys with inclined railroads, intended for transportation of molten metal or slag, poisonous or explosive substances and other dangerous goods, the use of friction and thumb couplings in lifting mechanisms is not allowed.

Another requirement is that the lifting mechanism must have two brakes – working and locking (activated after stopping the mechanism) [13, 15].

Table 1. *Guidelines for classification of bridge and gantry cranes and their mechanisms depending on the use of the crane (extract from BDS ISO 4301-5 for a crane in a steel foundry)*

Crane type	Crane classification group as a whole	Classification group of the mechanism as a whole		
		Lifting	Trolley traveling	Crane traveling
Crane in a rolling mill	A2	M4	M3	M4
Foundry (casting) crane	A7	M8	M6	M7
Shaft crane	A7	M8	M7	M7
Stripper crane	A8	M8	M8	M8
Furnaces loading crane	A8	M8	M8	M8

In the framework of a research contract with UCTM-Sofia, the authors have examined only those requirements that concern the gear trains of the mentioned mechanisms:

1. Provide a microspeed (slow speed) of the lifting mechanism, in accordance with the specifics of the processed dangerous goods.
2. Driving the mechanisms with two engines (motors), which are able to work independently in case of emergency (failure of one engine). This is especially important in metallurgical machines working with molten metal. If one engine fails, the other must be able to complete the operation so that the metal does not freeze in the bucket.

This article presents some solutions that meet the first requirement, in which a single-carrier planetary gear train (PGT) of the most often used type – $\overline{\mathrm{AI}}$-planetary gear train is involved (**Fig. 1**).

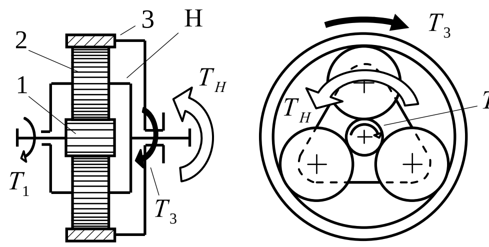

Fig. 1.*The most often used type planetary gear train –* $\overline{\mathrm{AI}}$*-PGT with one-rim planets with one external and one internal meshing*

2. $\overline{\mathrm{AI}}$-Planetary Gear Train and its Possibilities

2.1 Arrangement of $\overline{\mathrm{AI}}$-Planetary Gear Train

This type of most often used negative-ratio ($i_0 < 0$) planetary gear train (PGT) (Fig. 1) is signified in different ways. is signified in different ways. In many countries the Kudryavtsev's designation 2K-H is popular. It means two central gears (2K) and a carrier (H). In this article Prof. Tkachenko's designation is used [3, 4] as more detailed one (A for external and I for internal meshing, overline for one-rim planet).

As shown in Fig. 1 this gear train has 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 *planets* 2 which are housed in *carrier* H. Their number most often is k =3, more rare k = 2or 4, but in special cases there are PGTs with k = 20planets [3, 4]. However, planets number k does not affect the gear train's kinematics.Increasing the planets number (k >1) because of the torque sharing, leads to a few effects:

- Decreasing the overall dimensions and mass of the gear train;
- Decreasing the mesh load;
- Unloading the central element bearings – sun gear 1 and carrier H;
- Decreasing the noise level because of the lower peripheral velocities and higher accuracy of the smaller gears.

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.

2.2 Possible Ways of Working of $\overline{\mathrm{AI}}$-planetary gear train

This train, 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. In **Fig. 2a** and **2b** the six possible working modes in this case are shown – three modes as a reducer and three modes as a multiplier. Input power is denoted with P_A and output – with P_B. With a fixed carrier (ω_H = 0), the PGT works as pseudo-planetary. At F =2degrees of freedom (working as differential), six working modes are possible, too (**Fig. 2c** and **2d**) – 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 withF = 1degree 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 o – the ratio of the pseudo-planetary gear train working as reducer with fixed carrier (ω_H = 0)

$$i_0 = i_{13(H)} \qquad (1)$$

The speed ratios in the other cases of work with F = 1 degree of freedom (Fig. 2a and 2b) are expressed through it [3, 4].

Formula (1) applies to all types of PGTs.. For the $\overline{\mathrm{AI}}$-PGT considered here,basic speed ratio depends on number of teeth of the sun gear z_1 and the ring gear z_3 [3, 4]

$$i_0 = -\frac{z_3}{z_1} \qquad (2)$$

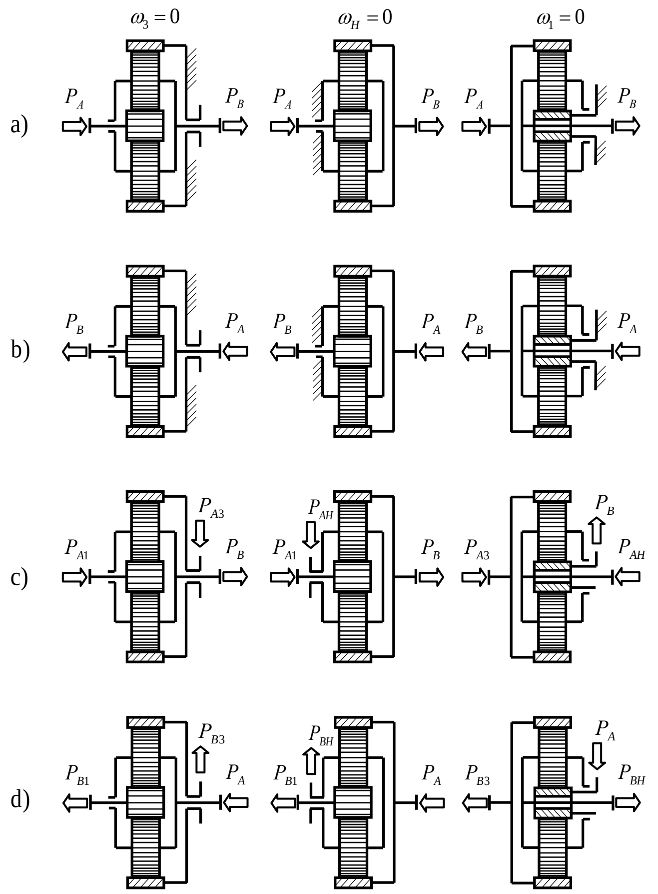

Fig. 2.*Working modes of$\overline{\mathrm{AI}}$-planetary gear train[3, 4]:*

With F = 1degree of freedom:
a) as a reducer (reduce the speed);
b) as a multiplier (multiply the speed).
With F = 2degrees of freedom (i.e. as differential):
c) as a summation PGT;
d) as a division PGT.

The above-mentioned advantages and capabilities are used in the mechanisms discussed in the article.

3. Microspeed providing

The lifting (hoisting) mechanisms of the cranes usually provide a microspeed around 20 - 25% of the main one[11, 14]. This is most easily achieved by changing the number of poles of the electric motor and hence its speed. When the asynchronous motor operates with one pair of poles, the synchronous speed (of the magnetic field) is 3000 min^{-1}, and when it operates with four pairs of poles – 750 min^{-1}. The operating speeds are slightly lower (approx. 2940 or 720 min^{-1}), depending on the power. If the microspeed thus achieved is not low enough, its required value must be achieved by a twin-motor drive and/or a suitable gear train design.

Fig. 3 shows an example of operation of a $\overline{\mathrm{AI}}$-planetary gear with F = 2 degrees of freedom, i.e. a differential that performs the summation of two movements from two electric motors [3, 4].

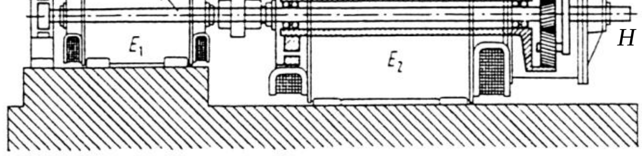

Fig. 3.*Twin-motor two-speed drive with an $\overline{\mathrm{AI}}$-PGT operating as summation differential [3]*

Although used primarily to provide microspeed, this arrangement has more scope to achieve more speeds of the output shaft:

1. Only the small motor $E_1$is running (the shaft 3 of the bigmotor E_2 is fixedby brake B_2) – a high speed ratio is obtained (**Fig. 4a**)

$$i_{13(H)} = i_0 = -\frac{z_3}{z_1}; \tag{3}$$

2. Only the big motor $E_2$is running (the shaft 1 of the small motor $E_1$is fixed by brake B_1) – a low speed ratio is obtained[3, 4] (**Fig. 4b**)

$$i_{3H(1)} = 1 - \frac{1}{i_0} = 1 + \frac{z_1}{z_3}; \tag{4}$$

3. Both motors operate simultaneously in one or in different directions – the obtained speed ratios depend on the basic speed ratio i_0 of the (**Fig. 4c**).

When the arrangement from Fig. 3 is used for two-speed drive (main and microspeed), the PGT operates in both variants in Fig. 4a and 4b.

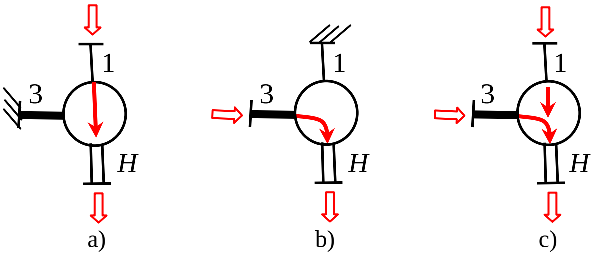

***Fig. 4.** Working modes of the PGT from figure 3*

Some cranes for dangerous goods require the microspeed to be much lower than the main one.

Fig. 5 shows the kinematic scheme of the gearbox (reducer) of a 200-ton container crane for Kozloduy nuclear power plant (NPP), manufactured by "BulmachineryEnterprices" - Radomir [3, 5]. It can perform two speed ratios i = 141 and i_m = 2228 for fast and slow speed (main and microspeed). In the large gear of the third gear stage a planetary gear train is built-in. The two speed ratios are carried out by operating only one of the motors.At main(fast) speed (Fig. 5a) the large motor is working, which drives the sun gear 1 of the PGT with fixed ring gear 3. At microspeed (slow speed) (Fig. 5b) the small motor is working, the ring gear 3 is driving, and the sun gear is fixed.In both cases, the carrier H is the output of the PGT. In **Fig. 6** the gearbox with removed top is shown.

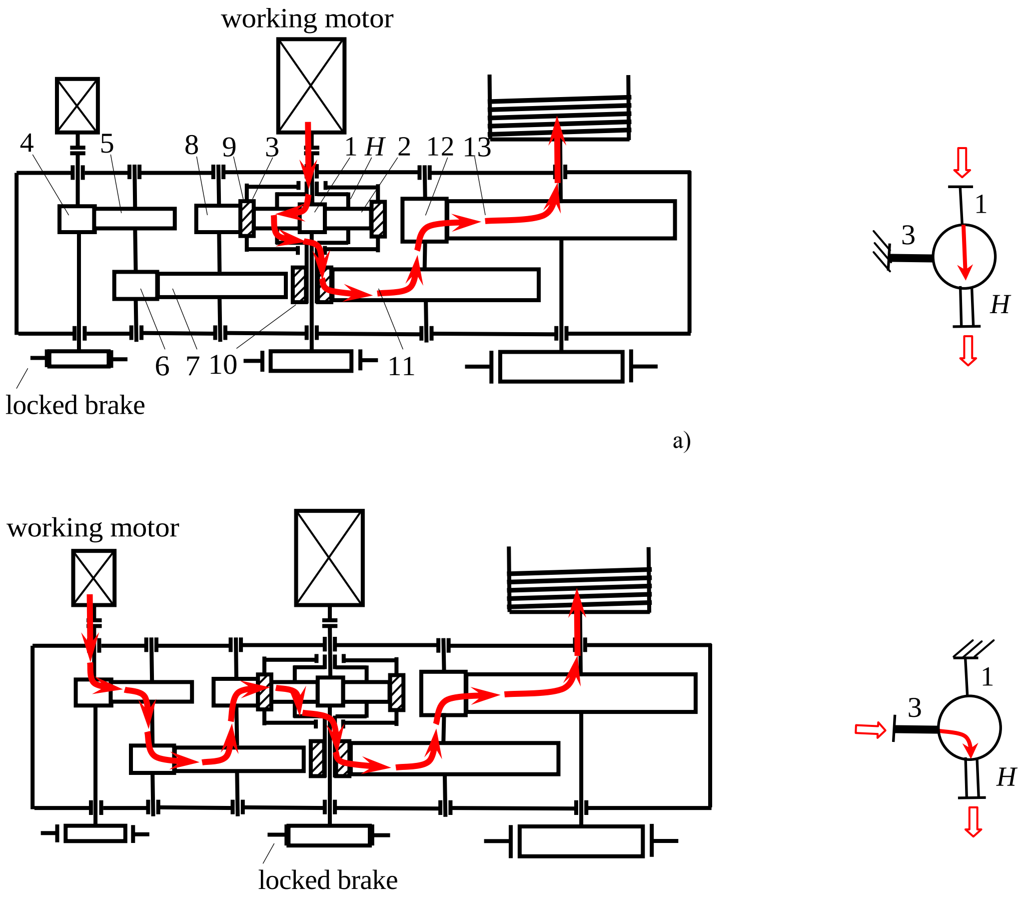

***Fig. 5.**Operation of* $\overline{\text{AI}}$*-PGT as a stage of a two-speed gearbox of a hoisting mechanism [3, 5]*

a) at main speed, speed ratio $i = 141$

b) at microspeed, speed ratio $i = 2228$

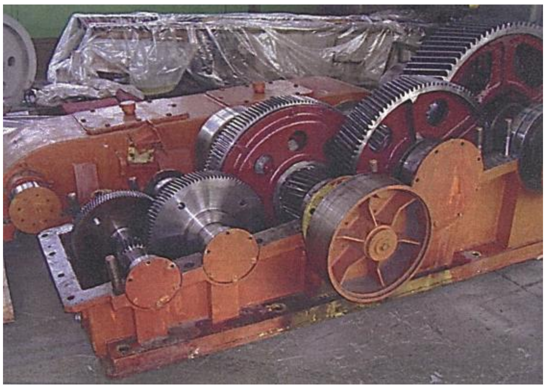

Fig. 6.*The gearbox from Fig. 5 [3, 4, 5]*

In the gearbox from Fig. 5 the PGT in both cases with F = 1 degree of freedom is working. Its speed ratios depend on the basic speed ratio i_0 defined in (2) and when operating at main speed (PGT operates with a fixed ring gear 3) it is

$$i_{1H(3)} = \left(1 - i_0\right), \qquad (3)$$

and when operating at microspeed (PGT operates with a fixed sungear 1) it is

$$i_{3H(1)} = 1 - \frac{1}{i_0}. \qquad (4)$$

With these values it participates in determining the speed ratio of the gearbox:

• Main speed:

$$i = i_{1H(3)} \cdot i_{10.11} \cdot i_{12.13} = \left(1 + \frac{z_3}{z_1}\right) \cdot \frac{z_{11}}{z_{10}} \cdot \frac{z_{13}}{z_{12}}. \qquad (5)$$

• Microspeed:

$$i_m = i_{45} \cdot i_{67} \cdot i_{89} \cdot i_{3H(1)} \cdot i_{10.11} \cdot i_{12.13} =$$
$$= \frac{z_5}{z_4} \cdot \frac{z_7}{z_6} \cdot \frac{z_9}{z_8} \left(1 + \frac{z_1}{z_3}\right) \frac{z_{11}}{z_{10}} \cdot \frac{z_{13}}{z_{11}}. \qquad (6)$$

Conclusions

Of the considered requirements for the lifting mechanisms of cranes for dangerous goods, two concern gears:

- Providing microspeed;
- Driving the mechanisms with two motors.

Due to their wide range of capabilities, planetary gears are suitable for embedding into these mechanisms. In the considered two arrangements the property of the most usual used $\overline{\mathrm{AI}}$-PGT to work with one and two degrees of freedom is used.

Acknowledgments

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