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MARINE RAM-TYPE STEERING GEARS MAINTAINABILITY INCREASING

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Abstract: The structure of steering gear's HATLAPA mechanism is analyzed. It is shown that presence of redundant constraints in it increases laboriousness of gear montage and respectively worsen maintainability. On the basis of provided analysis developed mechanism with reduced more than twice redundant constrainsts number.

KEYWORDS: steering gear; redundant constraints; mechanism; laboriousness; maintainability; self-alignment.

1 Introducing

Hydraulic steering gears are modern ships responsible elements which have to provide fail-safe functioning during all ship life cycle, because navigation safety generally depends from their efficiency. At the same time common ram-type gears have quite complicated lever mechanisms which cause high mutual arrangement requirements for its elements, significant laboriousness of montage, assembling, maintenance and respectively high building and operation costs. In machines which mechanisms contains redundant constraints, during operation taking place load redistribution which often occurs its overloads and failures. It could also cause technical characteristic changing, mechanical losses increasing and even jamming of movable parts. Therefore, in order to make mentioned things impossible, steering gears mechanisms with redundant constraints require constant supervision in operation, fitting and regulation operations, which additionally increases operation costs.

Thereby, decreasing redundant constraints quantity in steering gears mechanisms and its rational schemes creation is relevant and important task for mechanical engineering.

Redundant constraints excluding and mechanisms improving concerning metallurgical, lifting, transport machines, diesels and its elements considered in plenty of papers [1, 6, 9-11, 13, 14], but improvement steering gears mechanisms dedicated less number of researches [7, 8]. In mentioned works it is determined that guide beams presence in widely used steering gears constructions, which entered as rams unloading and around its own axis rotation excluding element is inexpedient because on its load capacity great influence makes gap between beam and ram footing connection. Thus, in P-18 steering gear in an gap absence guide beam takes 92,3% of

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lateral force and when gap increases to 0.5 mm – it takes only 20%. In YOOWON-MITSUBISHI YDFT-335-2 guide beam is element which only excludes rams rotation around its own axis. From the point of view of energetic efficiency, mentioned gears also are not excellent because of rams with tiller slider pairs connection. In previous works its also shown that in order to decrease redundant constraints number in steering gears it is advisable to refuse from guide beams, which leaves a reserve to analyze another gears designs and creating new ones.

Taking into account the above, the purpose of this paper is increasing ram-type steering gears maintainability through reduction redundant constraints number in its mechanisms.

The tasks of the paper are:

- to analyze structure of modern ram-type steering gear mechanism, to specify number and location of redundant constraints;

- to dissect redundant constraints presence influence on parts construction and gear maintainability;

- to decompose steering gear elements design influence on redundant constraints number and location;

- to propose new steering gear lever mechanism structural diagram where through redundant constraints number reducing it is possible to increase gear maintainability.

2 Methodology

In design of one of the modern steering gears HATLAPA R4ST-1000 (fig. 1) guide beam is absent (longitudinal beam is actually present but it is only the base for turning angle indicator) and used cylindrical sliders which form with tiller grooves two-movable cylindrical kinematic pairs B_4 and D_4 (fig. 2, where for simplification shown a half of steering gear mechanism), which exclude rams turning around their axis.

Those gear mechanism contains four movable links (n = 4) – ram, tiller, and two sliders with cylindrical working surfaces. Number of 5-class kinematic pairs here P_5 = 3 (O_5, C_5, I_5), number of 4-class kinematic pairs P_4 = 4 (A_4, B_4, E_4, D_4), number of 3, 2 and 1-class kinematic pairs $P_3 = P_2 = P_1 = 0$.



Fig. 1 General view of ram-type steering gear HATLAPA R4ST-1000

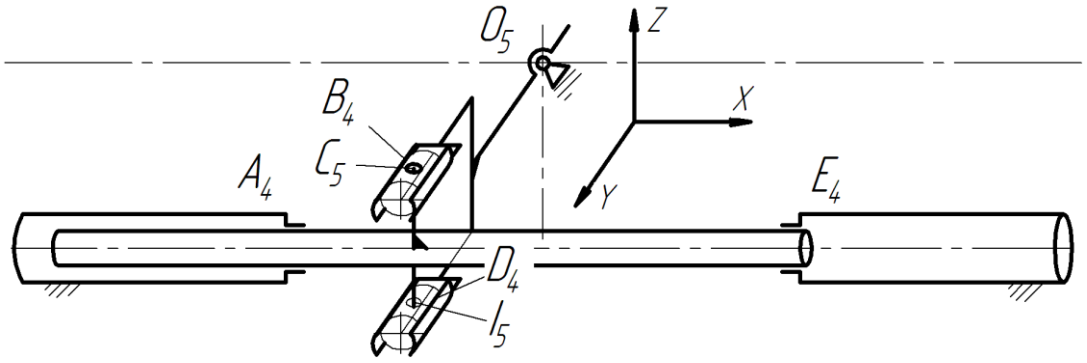


Fig. 2 Structural diagram of ram-type steering gear
HATLAPA R4ST-1000 mechanism (q = 8)

Total kinematic pairs number is:

$$P = P_5 + P_4 + P_3 + P_2 + P_1 = 3 + 4 + 0 + 0 + 0 = 7.$$

The sum of kinematic pairs movabilities:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times3 + 2\times4 + 3\times0 + 4\times0 + 5\times0 = 11.$$

Number of independent locked circuits [9]:

$$k = P - n = 7 - 4 = 3.$$

First independent locked circuit in driving mechanism – $O_5B_4C_5A_4O_5$, second one – $O_5D_4I_5E_4O_5$, third one – $C_5B_4D_4I_5C_5$.

Total mechanism mobility by Voinea and Atanasiu equation [12]:

$$W = f - \sum r_i = 11 - (4 + 4 + 2) = 1,$$

where $r_1 = r_2 = 4$, $r_3 = 2$ – independent locked circuits axis ranks.

Then redundant constraints number in basic variant by Somov and Malyshev formula [3, 4]

$$q_{SM} = W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n = 1 + 5\times3 + 4\times4 + 3\times0 + 2\times0 + 0 - 6\times4 = 8.$$

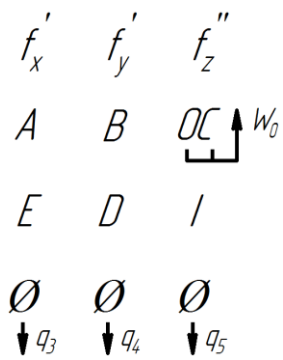
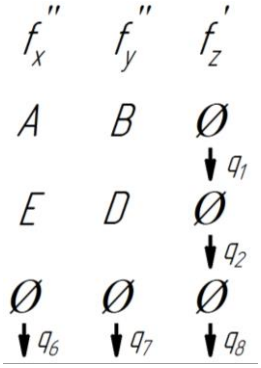
Redundant constraints number by Ozols formula [5]

$$q_{îZ} = W + 6k - f = 1 + 6\times3 - 11 = 8.$$

Thereby, total redundant constraints number in analyzed mechanism $q = q_{SM} = q_{îZ} = 8$, and generally in steering gear HATLAPA R4ST-1000 mechanism their number is q = 16.

Circuit method certifies obtained results and allows to determine redundant constraints type and location (table 1). Most of them (6, q_3 - q_8) located in third independent circuit $C_5B_4D_4I_5C_5$ which existence due to kinematic pairs D_4 and I_5 presence. These pairs here needed for excluding concentrated bending moment in the point of sliders axle C_5 and ram connection, which additionally to axial and lateral force could bending ram in the case of using one side slider. Thereby in this gear axial force from ram to tiller transmits by two streams through two sliders.

Table 1 Circuit method application to steering gear HATLAPA R4ST-1000 mechanism

Circuit	Planar movabilities f_{∂}	Non-planar movabilities f_n
$O_5B_4C_5A_4O_5$		
$O_5D_4I_5E_4O_5$		
$C_5B_4D_4I_5C_5$		
$W = 1,\ q = 8$		

3 Results and discussion

To dissect redundant constraints influence on parts construction and steering gear maintainability, main montage requirements were taken from manual [2] and summarized in a table 2. There in the first column name of redundant constraint is given, second one place content of redundant constrained influence on mechanism links self aligning capacity, third column contains possible ways of redundant constraint influence levelling in practice of design and operation. Last column contains consequences of such levelling absence which could take place as the result of montage, manufacturing, assembling, or operation imperfections.

Given in table. 2 analysis demonstrate redundant constraints presence on steering gear maintainability and proves their excluding from its design expediency. It will give the opportunities:

- to reduce requirements for steering gear foundation bearing surfaces and details mutual disposition and to lowering through this steering gear montage and assembling laboriousness and ship building capital costs;

- to decrease gaps between steering gear details and to increase through this load distribution evenness between them;

- to reduce steering gears producing, assembling, montage, operation and repair time and costs.

Considering steering gears mechanism development from the point of view increasing maintainability and providing maximum efficiency, the main directions to reduce redundant constraints number, taking into account performed analysis, will be following:

- organizing load transfer from each ram to tiller in single stream, excluding excessive sliders. This will reduce the number of kinematic pairs and independent circuits and, at location the center of kinematic pair “slider-groove” on ram axis, avoiding concentrated bending moment;

- excluding from steering gear mechanism guide beam like element prevents rams around its axis rotation. This also give opportunity to reduce the number of kinematic pairs and independent circuits in gear’s mechanism;

- providing rams and tiller grooves connection with rollers to reduce friction losses (like in FLUTEK-KAWASAKI steering gears (fig. 9)).

Table 2 Redundant constraints on steering gear HATLAPA R4ST-1000 design and maintainability influence

Redundant constraint	Redundant constraint presence influence	Practice way of redundant constraint influence levelling	Levelling absence consequences
1	2	3	4
q_1	Impossibility of hydrocylinders self-aligning along Z axis ($f_z^{'} = 0$) due to its housing bearing surfaces misalignment (fig. 3).	Control of z distances with accuracy ±0.15 mm. Achieve by pads under the housings installation.	Loading rams by bending moment and its seals by radial force in ZX plane. External oil leakages and seals destruction.
q_2			
q_3	Impossibility of sliders in tillers grooves self-aligning along X axis ($f_{\delta}^{'} = 0$) due to Δx grooves boring misalignment presence (fig. 4, a), axle holes in rams (fig. 4, b), or/and in sliders (fig. 4, c) displacement.	Gaps g_1 (between tiller grooves and sliders) or/and g_2 (between sliders axles and axle holes) increasing.	Uneven load distribution between sliders. Impossibility of mechanism assembling without of slider axle deformation in ZX plane and steering gear operation without slider axle bending deformation in ZY plane.
q_4	Impossibility of sliders in tiller grooves self-aligning along Y axis ($f_y^{'} = 0$) due to Δy axle holes in sliders(fig. 5, a) or/and sliders axles in rams displacement (fig. 5, b)	Gap g_2 between sliders axles and axle hole increasing.	Uneven load distribution between sliders. Impossibility of steering gear operation without slider axles bending deformation in ZX plane.
q_5	Impossibility of sliders in tiller grooves self-aligning around Z axis ($f_z^{''} = 0$) due to Δx grooves boring misalignment (fig. 4) or/and due to Δy axle holes in sliders or/and sliders axles in rams displacement (fig. 5).	The same as for redundant constraints q_3, q_4.	Impossibility of sliders turning around Z axis without slider axis bending deformation.
q_6	Impossibility of sliders in tillers grooves self-aligning around X axis ($f_{\delta}^{''} = 0$) due to tiller grooves boring angular misalignment $\Delta\chi$ (fig. 7, a) or due to non-perpendicularity sliders axle holes to sliders axles (fig. 7, b).	The same as for redundant constraints q_3, q_4.	The same as for redundant constraints q_3, q_4.

Table 2 contituation.

1	2	3	4
q_7	Impossibility of sliders in tillers grooves self-aligning around *Y* axis ($f_{ó}^{''} = 0$) due to tiller grooves middle plane to ram axles perpendicular plane $\Delta\gamma$ angular displacement (fig. 6).	The same as for q_1 redundant constraint, or the same for q_3, q_4 redundant constraints.	Impossibility of steering gear assembling and opereation without slider axles bending deformation in *ZX* plane.
q_8	Impossibility of sliders self-aligning along *Z* axis ($f_z^{'} = 0$) on their axles due to sliders Δz displacement (fig. 8, a) or tiller grooves boring misalignment (fig. 8, b).	Axle gap g_3 between sliders and their axle heads (fig. 8, c) increasing.	Impossibility of sliders and tiller assembling without *Z* axis directed deformation.

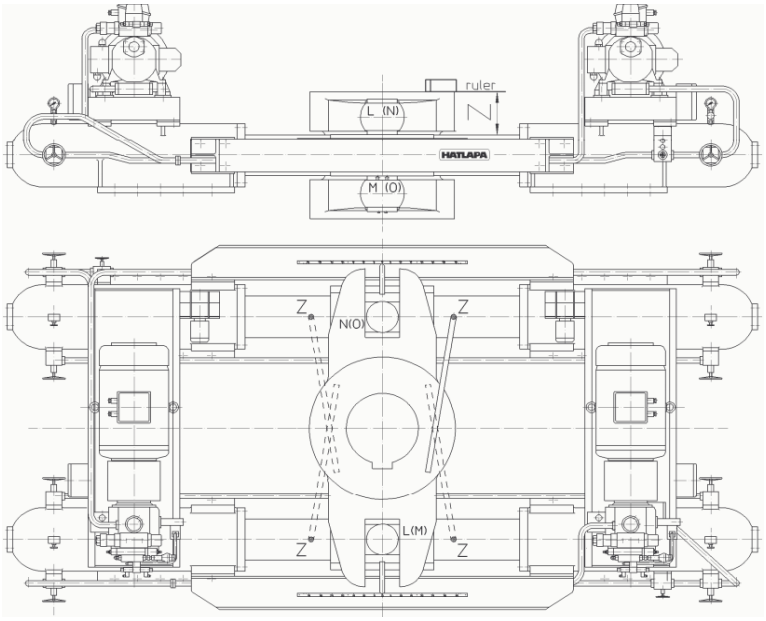


Fig. 3 Scheme of redundant constraints q_1 and q_2 influence practice levelling

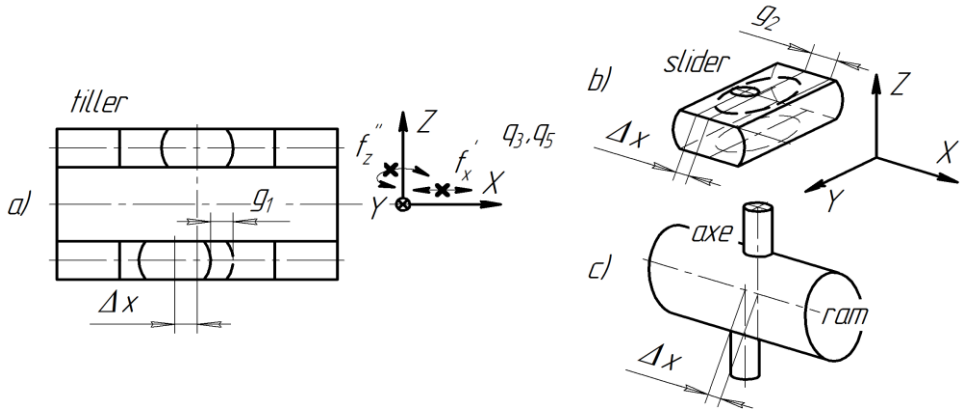


Fig. 4 Scheme of redundant constraints q_3 and q_5 influence practice levelling

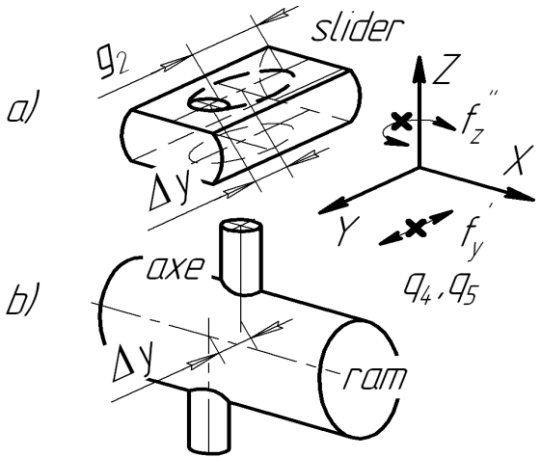


Fig. 5 Scheme of redundant constraints q_4 and q_5 influence practice levelling

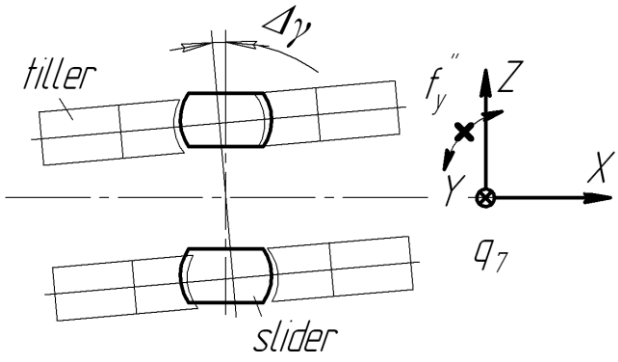


Fig. 6 Scheme of redundant constraint q_7 on mechanism assembling influence

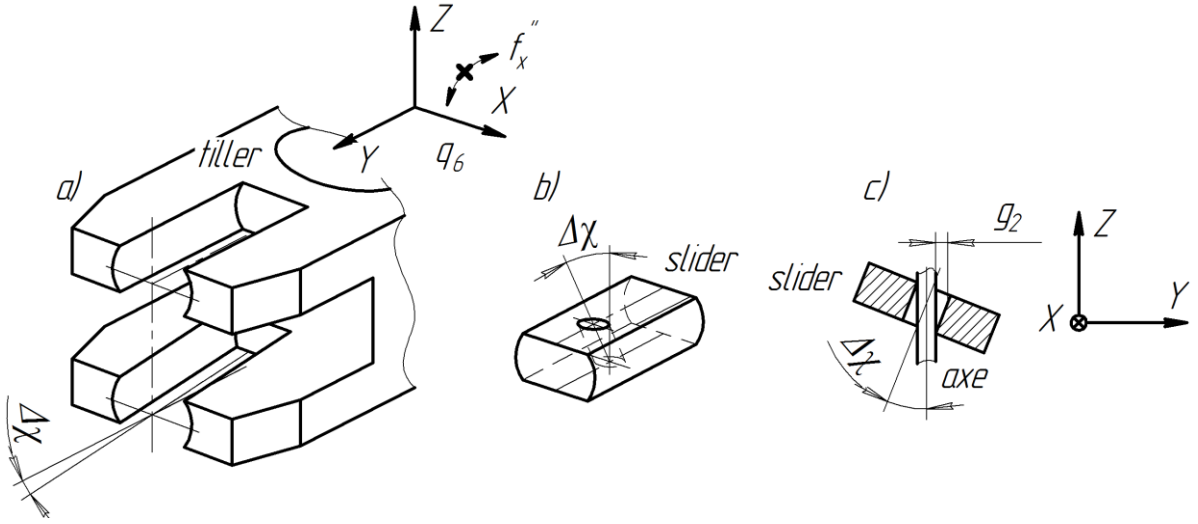


Fig. 7 Scheme of redundant constraint q_6 influence practice levelling

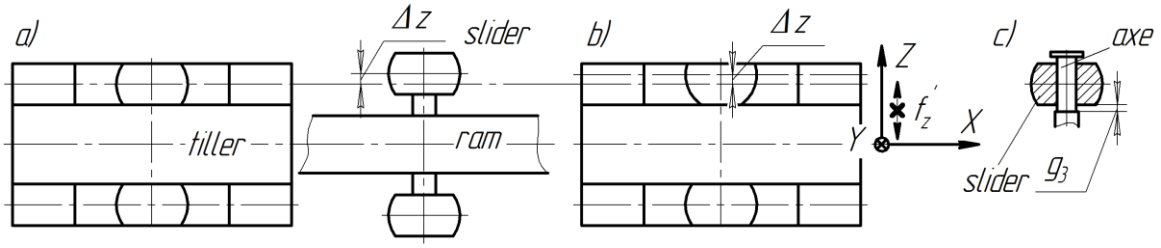


Fig. 8 Scheme of redundant constraint q_8 influence practice levelling

Taking into account proposed improving directions gave an opportunity to develop mechanism structural diagram depicted in fig. 10.

Each side rams there located parallel to each other with *e* eccentricity (could be in *ZX* or *ZY* plane) to prevent rams around its axis rotation and refuse through this of guide beams and sliders cylindrical surfaces. To reduce friction losses here used rollers instead of sliders.

Thereby mechanism contains three movable links (n = 3) – ram, tiller and roller. Number of 5-class kinematic P_5 = 1 (O_5), number of 4-class kinematic pairs P_4 = 3 (A_4, C_4, D_4), number of 3-class kinematic pairs P_3 = 0, number of 2-class kinematic pairs P_2 = 1 (B_2), and 1-class P_1 = 0.



Fig. 9 Rollers in FLUTEK-KAWASAKI steering gear design

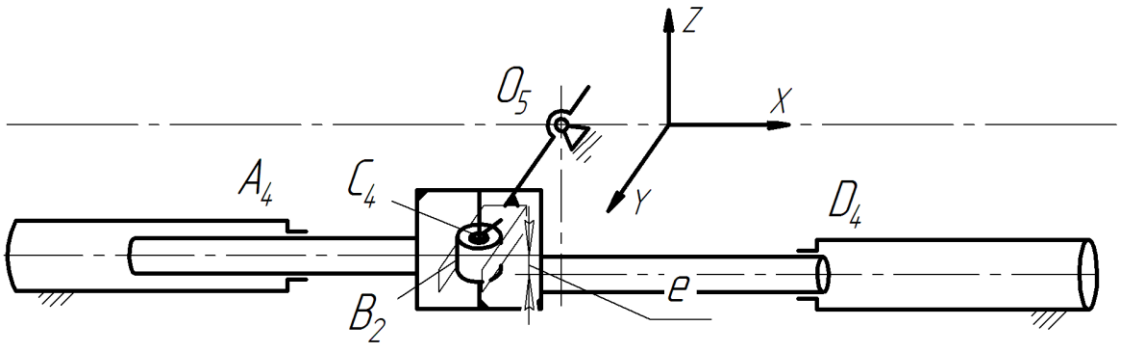


Fig. 10 Structural diagram of developed ram-type steering gear mechanism with reduced redundant constraints number (q = 3)

Total kinematic pairs number is:

$$P = P_5 + P_4 + P_3 + P_2 + P_1 = 1 + 3 + 0 + 1 + 0 = 5.$$

The sum of kinematic pairs movabilities:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times1 + 2\times3 + 3\times0 + 4\times1 + 5\times0 = 12.$$

Number of independent locked circuits:

$$k = P - n = 5 - 3 = 2\,.$$

First independent locked circuit – $O_5B_2C_4A_4O_5$, second one– $O_5B_2C_4D_4O_5$.

Total mechanism mobility:

$$W = f - \sum r_i = 12 - (5+5) = 2\,,$$

where $r_1 = r_2 = 5$ – independent locked circuits axis ranks.

Thereby developed mechanism has two mobilities ($W = W_b + W_l = 2$): basic mechanism mobility $W_b = 1$ and local roller mobility $W_l = 1$ (rotation around Z axis).

Redundant constraints number in basic variant by Somov and Malyshev formula:

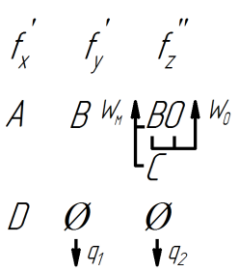
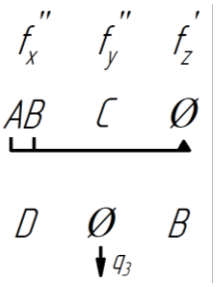
$$q_{SM} = W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n =$$
$$= 2 + 5\times1 + 4\times3 + 3\times0 + 2\times1 + 0 - 6\times3 = 3.$$

Redundant constraints number by Ozols formula:

$$q_{OZ} = W + 6k - f = 2 + 6\times2 - 11 = 3.$$

Circuit method verifies obtained results and allows to determine redundant constraints type and location (table 3).

Table 3 Circuit method application to developed steering gear mechanism

Circuit	Planar movabilities f_{∂}	Non-planar movabilities f_n
$O_5B_2C_4A_4O_5$		
$O_5B_2C_4D_4O_5$		
$W = 2,\ q = 3$		

Thereby, generally redundant constraints number in developed mechanism $q = q_{SM} = q_{\hat{I}\,Z} = 6$ (in steering gear HATLAPA R4ST-1000 mechanism their number is q = 16!).

Last three redundant constraints elimination in this construction is possible by using kinematic connections for rams with axle frame, where roller axle is fixed, connection. This improvement could cause additionally design complication, because in this case rams will turn to hinge console beams, which requires hydrocylinders significant design changing to provide lateral force reception.

Table 4 gives information about redundant constraints influence on gear with developed mechanism montage features. Comparison tables 3 and 4 content demonstrate that gear with developed mechanism has higher maintainability than prototype-gear and less requirements for parts manufacturing and assembling accuracy.

Table 4 Redundant constraints on developed steering gear mechanism design and maintainability influence

Redundant constraint	Redundant constraint presence influence	Practice way of redundant constraint influence levelling	Levelling absence consequences
q_1	Hydrocylinders self-alignment along *Y* axis and around *Z* axis impossibility ($f_{ó}^{'} = 0, f_{z}^{''} = 0$) due to its housings bearing surfaces misalignment.	Distances Y_1 and Y_2, control (fig. 11, a). Achieve by hydrocylinders housings during montage displacement in *XY* plane.	Loading rams by bending moment and its seals by radial force in *XY* plane.
q_2			
q_3	Hydrocylinders self-alignment around *Y* axis ($f_{ó}^{''} = 0$) за due to its housings bearing surfaces misalignment.	Distances Z_1 and Z_2 control (fig. 11, b). Achieve by pads under the housings installation.	Loading rams by bending moment and its seals by radial force in *ZX* plane.

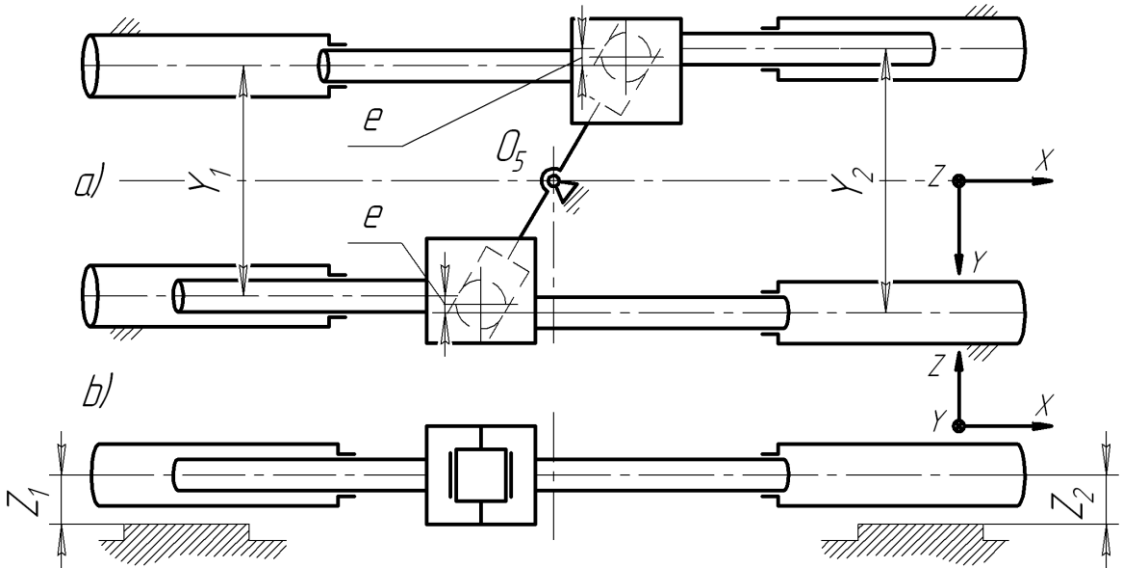


Fig. 11 Scheme of redundant constraints q_1 and q_2 influence in gear by fig. 10 practice levelling

CONCLUSION

Due to the presented in paper studies:

- it is shown than ram-type steering gear HATLAPA R4ST-1000 mechanism contains $q = 16$ redundant constraints;

- it is established that redundant constraints presence conditioned by two factors. Firstly by necessity of rams around its own axis rotation excluding – for this in HATLAPA steering gear design are used sliders and tiller grooves with cylindrical working surfaces, which forming low-class kinematic pairs that impose restrictions on mechanism movabilities. Secondly axial force from ram to tiller transmits by two streams through two sliders on both sides of rams, each of them adds independent locked circuit and, respectively, redundant constraints;

- on the HATLAPA steering gear example it is shown redundant constraints influence on parts construction and gear maintainability requirements. Revealed practice redundant constraints influence leveling ways – making tough montage accuracy requirements and gaps between gear parts increasing. This circumstances affects on steering gear montage and assembling laboriousness and ship building capital cost;

- new steering gear mechanism structural diagram developed, where redundant constraints number reduced more than twice (from 16 to 6) because of what became possible to decrease steering gear worth, montage, assembling laboriousness and load distribution between parts evenness.

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