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ON THE FORMAL FORCE ANALYSIS OF REAL MECHANICAL PARTS

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The purpose of the formal force analysis is the formalized determination of all the existing forces and moments that load every part of a real mechanical assembly (MA). This problem is treated in [1] to a certain degree, but the reasearch envelops only working forces (appearing during the work), assembling forces (appearing during the assembling process or the regulation process of the MA) and forces of weight, but the reasearch is only with the view to the quality.

A developement of a method for formal force analysis of a real MA (a drawing is included) is the purpose of the paper.

The method is based on the elaboration of an oriented graph of the force structure of the MA $G =< V, U >$, whose vertices V represent the numbers of the parts and the edges U represent the connections between the parts. A MA – reduction gear is suggested as an illustration in Fig.1, and its graph is represented in Fig.2. The following legend is accepted := completed immovable joint between two parts; – butt joint [the edge of the graph is oriented from the part with the smaller position number A to the part with the bigger position number B or from the part B to the part A if the movement of the removable part B toward the part A immovable by assumption for the assembly of MA is in direction $+x(y,z)$ or $-x(y,z)$]; – – – full movable joint; o - one of the parts envelops the other; $\odot$ – a bearing; Π – presence of an obstacle when the part moves in the direction indicated by the subscript and N – appearance of a new force. The analysis of a lot of examples permits the summary of the following

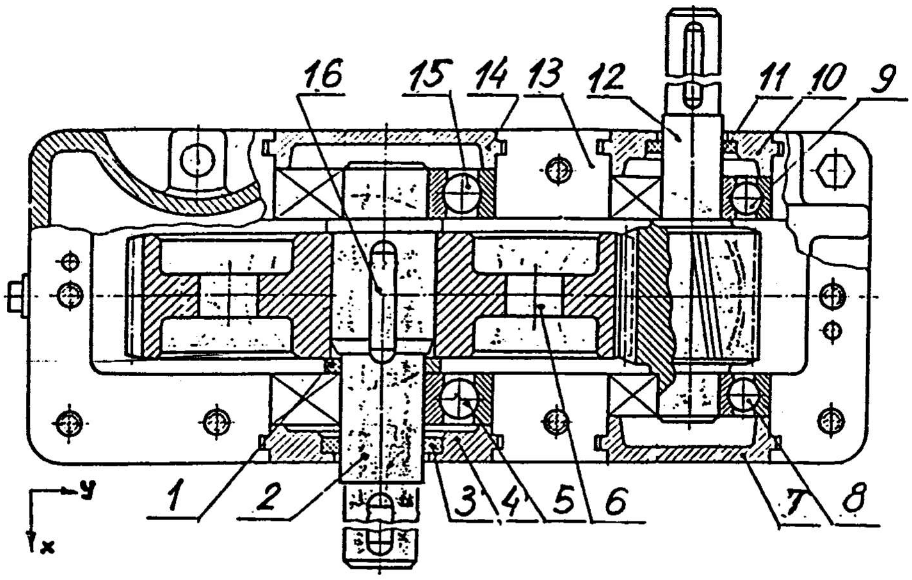

Fig. 1

Algorithm 1

1. The connections of MA are coded (Fig.1). A coordinate system code is chosen. The connections of each part with the next parts of the MA are marked ($1\alpha, 2\alpha, 2\alpha M, O\alpha, H\alpha, \Pi\alpha$, where α is the axis of assembly of the connection, and the position of the common normal of the connection ($n\|\alpha$;$ne\alpha$,β; $ne\alpha$, β, Γ).

2. An oriented graph of the force structure of the MA is elaborated (Fig.2). The pattern of the edges coresponds to the codes from p.1 (an edge $\alpha \to to1\alpha$; $\alpha = 2\alpha$; $M\alpha = 2\alpha M$; $- - -$ $O\alpha$; $OH\alpha$).

3. The entrances and the exits of the MA are determined. The entrance En and the exit Ex are the elements of the MA, that will form the connections with the external technical environment $E(ma - te)$. These connections aren't usually shown on the drawing of the MA.

4. The specific statements of the MA are determined. The statements of the MA in the process of its functioning, that are specific from point of view of the force are considered here.

5. The way of the force (algorithm 2) and the way of the moment (algorithm 3) are discovered by the graph of the MA

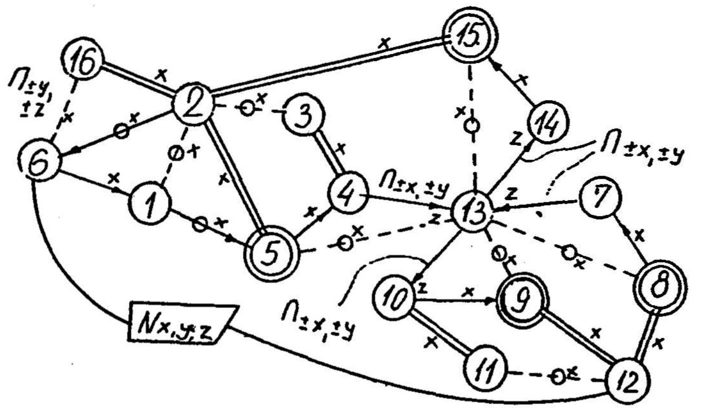

Fig. 2

Algorithm 2

Input data: $\pm F\alpha$, VF.

1. If the direction of $F\alpha \equiv +\alpha$ of the coordinate system p.2 is the next step. Otherwise the graph G have to be oriented to the opposite direction. Before going to p.2.

2. An oriented way SFi from VF to $E(ma - te)$ is looked for. The way can include: 1α with its direction and if the normal $n\|\alpha$; 2α and $2\alpha M$ without their direction. The following step will be: p.3 if only one way is found p.5 if the ways are two; p.6 if there is no way.

3. The way is discribed. The size of the force $|Fi|$ everywhere.

4. It is checked up if a new force appears. If the answer is positive a return to p.1 has to be done. The algorithm is ended if answer is negative.

5. The kind of the lever (force lever ordividing lever) is defined. The size of the forces $F\alpha 1$ and $F\alpha 2$ is found. The way SFi is discribed. The size of the force before the lever is $|Fi|$ and after it – $|F\alpha 1|$ and $|F\alpha 2|$. The next step is p.2.

6. The cycles Ci with direction $\beta(\Gamma)$ are checked up. Every cycle Ci envelops an oriented way, begining from VF and ending to VF. The way can envelops: $1\beta(\Gamma)$ with its direction and if the $n\|\beta(\Gamma)$, 2α and $2\alpha M$ without their direction. The next step will be p.7 only one way is found; p.8 if the ways are more then one; p.9 if there is no way.

7. The basic way SFi, that envelops totaly the cycle Ci (the force $F\alpha$ is

transmitted with friction) is discribed. The size of the force is $|F\alpha|$ everywhere. A return to p.4 has to be done.

8. The basic way SFi, that envelops totaly all the cycles (the force $F\alpha$ is transmitted with friction). The size of the force is $|F\alpha|$ everywhere. A return to p.4 has to be done.

9. A basic way SFi from VF to $E(ma-te)$ is looked for. The way can envelops. $H\alpha, 2$ and $2M$ without their direction. The way SFi is discribed. A return to p.4 is the next step.

Algorithm 3

Input data: $\pm M\alpha$, VM

1. The cycles Ci with direction α, enveloping VM are checked up. You have to go to: p.2, if there is no cycle; p.3 if there is one cycle at least.

2. The moment M is transmitted by the means of two (or more) forces opposite to each other $FM1$ and $FM2$. The forces have a direction $\beta(\Gamma)$ and the distance between them his equal the distance between the respective contacting elements of the part VM. The size of $FM1$ and $FM2$ is: $|FM1| = |FM2| = M\alpha/h$. The forces $FM1$ and $FM2$ are transmitted following the algorithm 2.

If the forces $FM1$ and $FM2$ reach the some part, but they don't reach the $E(ma-te)$ than they have to be considered as moments and a return to p.1 has to be done.

3. The combination of all non-isolate cycles Ci, enveloping VM is considered. The moment is transmitted by friction and it passes from one part to another over all the cycle $Ci(\Sigma Ci)$, i.e. there is a friction moment across the connections of $Ci(\Sigma Ci)$. The size of the moment is $|M\alpha|$ everywhere. The way is discribed. If $M\alpha > Mc$, where Mc is the connection moment, that moment connection can be transmitted, and the next step is p.4. The algorithm is ended if $M\alpha < Mc$.

4. A disoriented way is checked up. The way envelops 2; $2M$; $H\beta(\Gamma)$, $n||\beta(\Gamma)$ (but one of the two vertices of $H\beta(\Gamma)$ have to be a part, number which quantity in the specification of the assembly drawing is $k \geq 2$) and obstacles $\Pi\beta(\Gamma)$; N. The size of the moment is $|M\alpha - Mc|$ everywhere and if new forces appear it is $Fi = (M\alpha - Mc)/h$ when the moment is transmitted by $H\alpha(\beta)$. The algorithm is ended.

Note: The algorithm 2 and algorithm 3 are simplified because of lack of space.

The suggested algorithms permit the formal determination of the way of six kind of forces and moments (working, assembling, weight, friction, inertia and heat).

The assembling forces and the heat forces are specific forces and they will be considered below.

Assembling forces

A combination of relatively immovable parts (assemblies) is often created where the process of assembly is performed. The immobility is secured by using of an assembling force for example a bolted joint. The introduced assembling force stays in the combination and it is balanced in the parts of the assembly. The way of the force will be a cycle because the force is balanced in the graph G. That cycle can be named an assembling cycle following the kind of the force.

Statement 1. *The forces (moments) of an assembling cycle present a closed vectorial cycle, i.e. they are balanced.*

Proof. Let the contrary statement be correct, i.e. the forces (moments) don't present a closed vectorial cycle that means their main vector $R' \rightarrow$ and their main moment $Mo' \rightarrow$ are differend from zero. According to the statement 9 [2] $R' \rightarrow$ and $Mo' \rightarrow$ are transmitted to another MA or to the ground, but that can't be done because the MA isn't assembled to the other MA nor to the ground.

Heat forces

The heat forces appear from the heat expansion of parts and the impossibility of any following expansion because the clearance which exists in the assembly is equal to zero. Therefore the way of the heat forces is a cycle. It must be noted that this cycle represents the respective assembling tolerance chain.

The illustration of the algorithms is shown in Fig.1 and Fig.2.

If the force $F1$ acts in the direction $+x$; the part–entrance En is 12 and the part–exit Ex is 13, then the way of Fi is $12-8-7-13$. The way of the force $F2(-x, En-12, Ex-13)$ is $12-9-10-13$ and the way of the force $F3(+y, En-12, Ex-13)$ is $12-9-13-12-8-13$.

The way of the moment $M1(\pm x, En-12, Ex-2or13)$ is $2-6-1-5-2-16-6-12$.

The way of the heat force $H1$ from the part 5 $(\pm x, En-2, Ex-2)$ is $2-6-1-5$. If the connection $2-5$ is destroyed $2-5-4-13-14-15-2$.

Assembling forces: $2-6-1-5-2$; $2-6-1-5-4-13-14-15$; $12-8-7-13-10-9-12$.

Conclusions

A method for formal determination of the way of six kinds of forces and moments (working, assembling, weight, friction, inertia and heat) is presented. That permits to discover all the forces and moments in the quantitive and qualitative aspects which load up all the parts of the assemblies, when the incoming forces are known.

The method is basis for the solution of the opposite task: the elaboration of an oriented graph from a new assembly.

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