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ANALYSIS OF THE MAIN SHAFT BEHAVIOUR AT OPTIMIZED WINCH HAULAGE

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ABSTRACT
The Winch Haulage is an engineering system which is described by set of quantities. The dynamic model of its main shaft is build based on such quantities - some of them are considered as fixed and called parameters and the other quantities are treated as variables.
The behaviour of the shaft's dynamic model is subjected to stiffness, loading and geometric constraints, while mathematical model calculates strain and stresses, deflection and displacement, etc. For the analysis of the adopted model(s) the Finite Element Method has been used in this paper. FEA methodology was applied at adopted model with 'real' and optimized dimensions.
The results that are graphically presented for both cases have been compared bringing to the conclusion that shaft's adopted model at optimized winch haulage fulfils exploitation criteria and is a good base for the modification of the device.
Key words: Shaft of Winch Haulage, Beam Element, Displacement and Deflection, Finite Elements

1. INTRODUCTION
Constructive parameters of shaft that must be fulfilled in order to complete the working criteria are: shaft sizes, rotation moment, safety coefficient, angle of torsion, displacement of shaft and critical number of rotation.
The selection of the optimum shaft model should also fulfill constraints in order that: the shaft must be in function of winch haulage, and its installation must provide given functions.
Shaft as a part of winch haulage should also execute technical conditions towards: the other parts of winch haulage, coefficient of usefulness, and the safety coefficient.
Its design process presents a "provocation" and "challenge" for an engineer – designer/constructor, who among many tasks needs to make many decisions for getting "the best" solution.
The design is a process with many questions coming up one after another, starting from problem/task introduction, design process itself and those related directly to technology or science. The designer needs to think, wonder and decide when solving design problems. This complex task should be put through a procedure/methodology with certain stages that can be used during all design process with needed accuracy that will bring to successful finalization of the design.
In the paper is described FEA methodology was applied at adopted model with 'real' and optimized dimensions.
The results that are presented for both cases have been compared bringing to the conclusion that shaft's adopted model at optimized Winch Haulage fulfills exploitation criteria and is a good base for the modification of the device.

2. FINITE ELEMENT ANALYSIS OF THE SHAFT

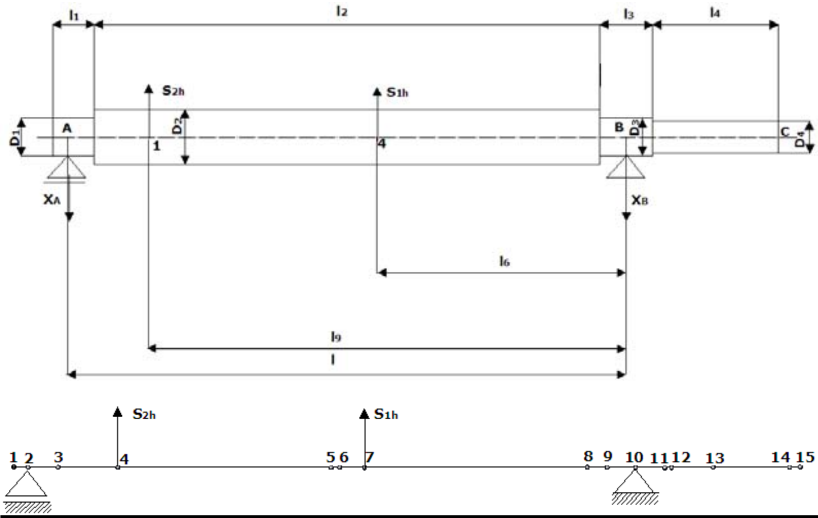
The Winch Haulage is an engineering system which is described by set of quantities, based on which the dynamic and optimization model of its main shaft is build [1, 3]. Values of the current and optimal diameters are presented in Table 1.

Table 1. Difference between the values of the model, optimal values and absorption values

Values of	D_1	D_2	D_3	D_4	l_2	S	φ	f	Objective function - volume
model	280	360	280	240	3787.5	1.866794	0.007934	17.57546	471365190.1
optimal	279.65	334.639	279.654	240.274	3729.867	1.499404	0.008841	13.11552	413880335.4
adopted	280	335	280	240	3730	1.504262	0.008834	13.22399	414611729.7

The Winch Haulage's shaft is subjected to bending, tension, torsional loads and magnetic forces acting in combination with one another. When they are combined, both static and fatigue strength are to be important design considerations, since shaft may be subjected to static stresses, completely reversed stresses and repeated stresses, all acting at the same time.

The different quantities influencing in the shaft design either are adopted from tables or are calculated during the creation of mathematical model for the adopted geometrical model of the Winch Haulage's shaft.

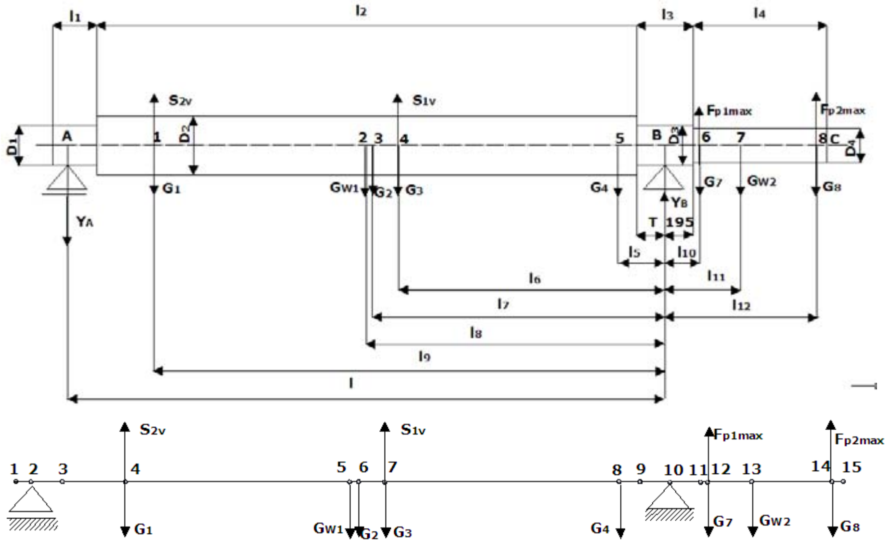


HORIZONTAL PLANE								
	Nodes		L[m]	D[m]	$E[kN/m^2]$	$I[m^4]$	Loads	
Nr. Ele.	i	j	Current/optimal	Current/optimal		Current/optimal	F[kN]	M[kN*m]
e1	1	2	0.11/0.11	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}$ / $6.034371169\cdot10^{-4}$	0	0
e2	2	3	0.2/0.2	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}$ / $6.034371169\cdot10^{-4}$	0	0
e3	3	4	0.4075/0.37	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	0	0
e4	4	5	1.48625/1.48625	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	18.62	0
e5	5	6	0.04375/0.04375	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	0	0
e6	6	7	0.19/0.19	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	0	0
e7	7	8	1.53/1.53	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	43.2	0
e8	8	9	0.13/0.11	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}$ / $1.236457299\cdot10^{-3}$	0	0
e9	9	10	0.2/0.2	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}$ / $6.034371169\cdot10^{-4}$	0	0
e10	10	11	0.195/0.195	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}$ / $6.034371169\cdot10^{-4}$	0	0
e11	11	12	0.05/0.05	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}$ / $3.257203263\cdot10^{-4}$	0	0
e12	12	13	0.284/0.284	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}$ / $3.257203263\cdot10^{-4}$	0	0
e13	13	14	0.543/0.543	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}$ / $3.257203263\cdot10^{-4}$	0	0
e14	14	15	0.061/0.061	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}$ / $3.257203263\cdot10^{-4}$	0	0

Figure 1. Mechanical and FE model with respective data-horizontal plane

For analysis of the shaft the beam element was considered. The beam element is a two-dimensional finite element where the local and global coordinates coincide. It is characterized by linear shape function. The beam element has modulus of elasticity ***E***, moment of inertia ***I*** and length ***L***. Each beam element has two nodes.

The shaft model for finite element analysis for both planes has the same number of elements and nodes: fourteen beam elements and fifteen nodes as a result of loads and diameter. The data for each element, and loads in nodes are given in Fig. 1 and Fig. 2 for respective planes, while displacements and deflections calculated with FE Matlab software modules, [4] for each node in respective plane their resultants are given in Table 2.



VERTICAL PLANE								
	Nodes		L[m]	D[m]	$E[kN/m^2]$	$I[m^4]$	Loads	
Nr. Ele.	i	j	Current/optimal	Current/optimal		Current/optimal	F[kN]	M[kN*m]
e1	1	2	0.11/0.11	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}/6.034371169\cdot10^{-4}$	0	0
e2	2	3	0.2/0.2	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}/6.034371169\cdot10^{-4}$	0	0
e3	3	4	0.4075/0.37	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	0	0
e4	4	5	1.48625/1.48625	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	35.99	0
e5	5	6	0.04375/0.04375	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	33	0
e6	6	7	0.19/0.19	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	35.75	0
e7	7	8	1.53/1.53	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	6.16	0
e8	8	9	0.13/0.11	0.36/0.335	$2\cdot10^8$	$1.648959152\cdot10^{-3}/1.236457299\cdot10^{-3}$	34.75	0
e9	9	10	0.2/0.2	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}/6.034371169\cdot10^{-4}$	0	0
e10	10	11	0.195/0.195	0.28/0.28	$2\cdot10^8$	$6.034371169\cdot10^{-4}/6.034371169\cdot10^{-4}$	0	0
e11	11	12	0.05/0.05	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}/3.257203263\cdot10^{-4}$	0	0
e12	12	13	0.284/0.284	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}/3.257203263\cdot10^{-4}$	7.935	0
e13	13	14	0.543/0.543	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}/3.257203263\cdot10^{-4}$	3.885	0
e14	14	15	0.061/0.061	0.24/0.24	$2\cdot10^8$	$3.257203263\cdot10^{-4}/3.257203263\cdot10^{-4}$	8.741	0

Figure 2. Mechanical and FE model with respective data-vertical plane

3. CONCLUSION

Comparing the values for displacement and deflection of each mode of the model in horizontal and vertical plane, fig.1 and fig.2 and resultants, table 2, for current and optimal diameters and lengths, table 1 and referring to equation displacement:

$$f_l = (0{,}3 \ldots 0{,}5) \cdot 10^{-3} \cdot l \tag{1}$$

Table 2. Results for displacements and deflections

		Vertical plane		Horizontal plane		Resultants	
		Current	Optimal	Current	Optimal	Current	Optimal
Node		x e10-6		x e10-6		x e10-6	
1	Displacement	-0.019	-0.0196	0.0452	-0.025	0.049031	0.031767
	Deflection	0.1725	0.1781	0.4107	0.2277	0.445456	0.289079
2	Displacement	0	0	0	0	0	0
	Deflection	0.1725	0.1781	0.4107	0.2277	0.445456	0.289079
3	Displacement	0.0339	0.0352	0.0814	0.0452	0.088177	0.057289
	Deflection	0.1635	0.1723	0.3995	0.2219	0.431662	0.280939
4	Displacement	0.0958	0.1024	0.2232	0.1241	0.242891	0.160893
	Deflection	0.1364	0.1548	0.3608	0.2015	0.385722	0.254097
5	Displacement	0.1574	0.2337	0.5189	0.2969	0.542247	0.377843
	Deflection	-0.0741	0.0035	-0.0095	0.0061	0.074706	0.007033
6	Displacement	0.154	0.2337	0.5181	0.297	0.540503	0.377922
	Deflection	-0.0819	-0.0026	-0.0245	-0.0019	0.085486	0.00322
7	Displacement	0.1353	0.2306	0.5074	0.2932	0.525129	0.373018
	Deflection	-0.1136	-0.0304	-0.0869	-0.0381	0.143026	0.048742
8	Displacement	0.058	0.0562	0.1122	0.0679	0.126305	0.088141
	Deflection	-0.1701	-0.1661	-0.361	-0.2145	0.399068	0.271292
9	Displacement	0.0355	0.0344	0.0723	0.0441	0.080545	0.05593
	Deflection	-0.1757	-0.1689	-0.3639	-0.2176	0.404096	0.275458
10	Displacement	0	0	0	0	0	0
	Deflection	-0.1743	-0.1733	-0.3547	-0.2219	0.395212	0.281554
11	Displacement	-0.0326	-0.0338	-0.0692	-0.0433	0.076494	0.05493
	Deflection	-0.1615	-0.1733	-0.3547	-0.2219	0.389736	0.281554
12	Displacement	-0.0406	-0.0425	-0.0867	-0.0544	0.095735	0.069033
	Deflection	-0.1573	-0.1733	-0.3479	-0.2219	0.381808	0.281554
13	Displacement	-0.0428	-0.0449	-0.1811	-0.1174	0.186089	0.125693
	Deflection	-0.1563	-0.1733	-0.3194	-0.2219	0.355593	0.281554
14	Displacement	-0.1205	-0.139	-0.3474	-0.2379	0.367705	0.275531
	Deflection	-0.1365	-0.1733	-0.2996	-0.2219	0.32923	0.281554
15	Displacement	-0.1288	-0.1496	-0.3657	-0.2515	0.387719	0.29263
	Deflection	-0.1365	-0.1733	-0.2996	-0.2219	0.32923	0.281554

It can be noticed that:

-Displacements and deflections at optimal model have higher values for vertical plane,

-Displacements and deflections at optimal model have lower values for horizontal plane,

-Displacements and deflections at both current and optimal model have higher values for horizontal plane comparing to vertical one,

-Resultants displacements and deflections at optimal model have lower values comparing to current;

Based on what and in equation (1) can be concluded that values for displacements and deflections at optimal model are within allowed limits and satisfactory.

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