ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2673

INVESTIGATION OF THE INFLUENCE OF THE LENGTH OF THE FLEXIBLE ELEMENT ON THE DYNAMIC LOADING IN LIFTING DEVICE

Toni UZUNOV

University of Ruse, Bulgaria

ABSTRACT:
A programme for investigation of the dynamic loading of the elements of lifting device depending on the length of the flexible element is developed. Numerical experiments are carried out using the developed programme. An experimental facility on the base of electrical wire rope hoist is realized and experiments are carried out and values are received for the dynamic factor of the transitional processes. The reliability of the mechanical and mathematical equations is proven using the values received for the dynamic factor from the experiments and from the numerical experiments.

KEYWORDS:
Lifting device, dynamic processes, dynamic factor

1. INTRODUCTION

In existing tendencies for high level of usability of the construction materials, it is necessary to know exactly and take into account the dynamic loads. This is especially important for the lifting devices because of their repeated and short-term operation mode and variable loads of their components. The dynamic forces arising in the “drive – flexible element – load” system load the whole kinematical chain and all supporting elements of the device and supporting structures of the appliances. The investigation of the transitional processes may be used as criteria in analysis of the quality of the drive mechanism and in selection of the motor, brake and related components parameters [1], [2].

Mechanical and mathematical equations are developed for investigation of the influence of the times of the transitional processes on the dynamic loads of the components of lifting devices [5]. The equations for the hardness factor *c* and damping factor *d* of the elastic system of the rope length of lifting device of electrical wire rope hoists [3] are determined experimentally.

Using the frequency control of the lifting devices with the developed mechanical and mathematical equations, appropriate times of the transitional processes depending on the lifting height may be developed and realized, in order to achieve minimum dynamic loads. Thus, the maximum amplitudes of inertia forces may be reduced as well as the amplitudes of fading oscillations which advantages the force loading of the components of the lifting device and metal construction.

The subject of this work is to investigate the influence of the rope length on the vertical oscillations of the load and dynamic load of the components of the lifting device.

2. EXPOSITION

Using the developed mechanical and mathematical equations a program is developed on the base of MATLAB software for investigation of the influence of the length of the flexible element on the dynamic load of the lifting device components.

Numerical experiments are carried out for lifting device of electrical wire rope hoists with the following technical specifications: rated load capacity m=500 kg; lift height H=9 m; lifting height v=8 m/min; motor power P=0,75 kW; average starting moment of the motor M_{mot}=17,3 Nm; braking moment M_b=15 Nm; resistance moment caused by the load weight reduced to the motor shaft M_s=5,67 Nm; drum diameter D=0,179 m; gear ratio and tackle u_r=33,284 and u_p=2, respectively; mass moments of inertia of the rotor and clutch J_r=0,008 kg.m^2 and J_c=0,0025 kg.m^2.

The values of the hardness factor *c* and damping factor *d* of the “rope – electrical hoist – metal structure” system are received using the calculated empirical equations $c = f(L)$ and $d = f(L)$ [3]

$$c = 2011491{,}889L^{-0{,}679}; \qquad (1)$$

$$d = 4609{,}026L^{-0{,}416}, \qquad (2)$$

where *L* is the rope length, m.

In Table 1 there are given the results received from the numerical experiments for the parameter values characterizing the dynamic processes.

Table 1. Results from numerical experiments

Rope length *L*, m	Hardness factor *c*, N/m	Damping factor *d*, kg/s	Natural frequency of the system p_o, s^{-1}	Fading factor *k*, s^{-1}	Period of the fading oscillations *T*, *s*	Maximum dynamic factor k_d
1	3247970	4609	83.638	4.971	0.078	1.293
2	1822200	3455	62.685	3.725	0.102	1.375
3	1300400	2919	52.956	3.147	0.117	1.369
4	1023600	2589	46.983	2.792	0.129	1.361
5	850180	2359	42.818	2.545	0.141	1.351
6	730520	2187	39.691	2.359	0.152	1.336
7	642590	2051	37.226	2.212	0.163	1.322
8	575020	1941	35.214	2.093	0.174	1.304
9	521340	1848	33.531	1.993	0.184	1.294
10	477590	1769	32.092	1.907	0.193	1.290
11	441180	1700	30.845	1.833	0.201	1.272
12	410370	1639	29.748	1.768	0.209	1.265
13	383930	1586	28.774	1.711	0.218	1.261
14	360970	1538	27.901	1.684	0.225	1.258
15	340840	1494	27.271	1.638	0.228	1.252
16	323020	1455	26.886	1.598	0.234	1,249
17	307130	1418	26.263	1.561	0.239	1,245
18	292860	1385	25.694	1.527	0.245	1.241

The values of maximum dynamic factor are calculated according to the following equation:

$$k_d = \frac{F_{max}}{Q_n + G}, \qquad (3)$$

where F_{max} is the maximum dynamic force in the elastic link in the transitional processes at given rope length, N; Q_n – rated load capacity , N; *G* – the weight of the load-catching device, N.

Through the technical specifications of the electrical hoist the values of the acceleration times for lifting and lowering are received, respectively $t_m^{\uparrow} = 0{,}109\ s$ and $t_m^{\downarrow} = 0{,}056\ s$ and for the stopping at lifting $t_b^{\uparrow} = 0{,}071\ s$ and at lowering $t_b^{\downarrow} = 0{,}194\ s$. Smaller values of the first three times suppose arising of relatively greater dynamic forces during the transitional processes in comparison with the stopping at lowering process as the time $t_b^{\downarrow}$ is considerably greater than the other times.

It is found that the values of dynamic loads depends on the ratio of the acceleration time or deceleration time $t_{m(b)}$ and the period *T* of the fading oscillations of the load and lowest values for the dynamic loads are received at $t_{m(b)} = T, 2T, \ldots$ and the loads are highest at $t_{m(b)} = T/2, 3T/2, \ldots$ [5].

The part of the results received through numerical experiments is shown on the Figure 1 as graphical images of the change of the force *F* caused by load weight with the lifting device operation at rated load with a weight of *500* kg for different rope length *L*. The forces F_{maxi}, shown at Figure 1 at *L=2 m* are the maximum amplitudes of the forces that arise in the rope branches and the indexes 1 and 2 are for the lifting, resp. lowering processes, and stopping and the indexes 3 and 4 are for start and stop at lowering the loads.

When compare the times $t_m^{\uparrow}$, $t_m^{\downarrow}$ and $t_b^{\uparrow}$ of the transitional processes with their table values for the period *T* of the fading oscillations of the loads and from the analyses of the graphs on Fig. 1, the following is found:

- At rope length *L*=1÷8 *m* the duration of the period *T* of the fading oscillations of the load is changed over 2 times, and in case of *L*=9÷18 *m*, the change of *T* is lower than 1,3 times.
- The influence of the period *T* over the dynamic loads of the lifting device is more sensible at lower rope lengths when the value of *T* is commensurable with the times $t_m^{\uparrow}$, $t_m^{\downarrow}$ and $t_b^{\uparrow}$ for the transitional processes.
- The highest disturbance force is generated in the process of acceleration during lowering of the load and at a rope length *L*=2÷3 *m* it reaches maximum values with dynamic factor $k_d = 1{,}375$, as the acceleration time is $t_m^{\downarrow} \approx 3T/2$.

- The decrement of fading oscillations is highest in the processes of starting and stopping during lifting of load for rope length respectively *L*=2 *m* and *L*=1 *m* when $t_m^{\uparrow} \approx T$ and $t_b^{\uparrow} \approx T$.
- In the process of stopping during lowering the fading oscillations of the load have the highest amplitudes with rope lengths *L*=1 *m* and *L*=4 *m* when $t_b^{\downarrow} = 5T/2$, respectively $t_b^{\downarrow} = 3T/2$, and with *L*>7 *m* the amplitudes of fading oscillations are minimum because $t_b^{\downarrow} \approx T$.
- In case of rope lengths *L*>12 *m* the dynamic factor have minimum values because the period *T* of the load oscillations is considerably higher than the times $t_m^{\uparrow}$, $t_m^{\downarrow}$ and $t_b^{\uparrow}$ of the transitional processes.

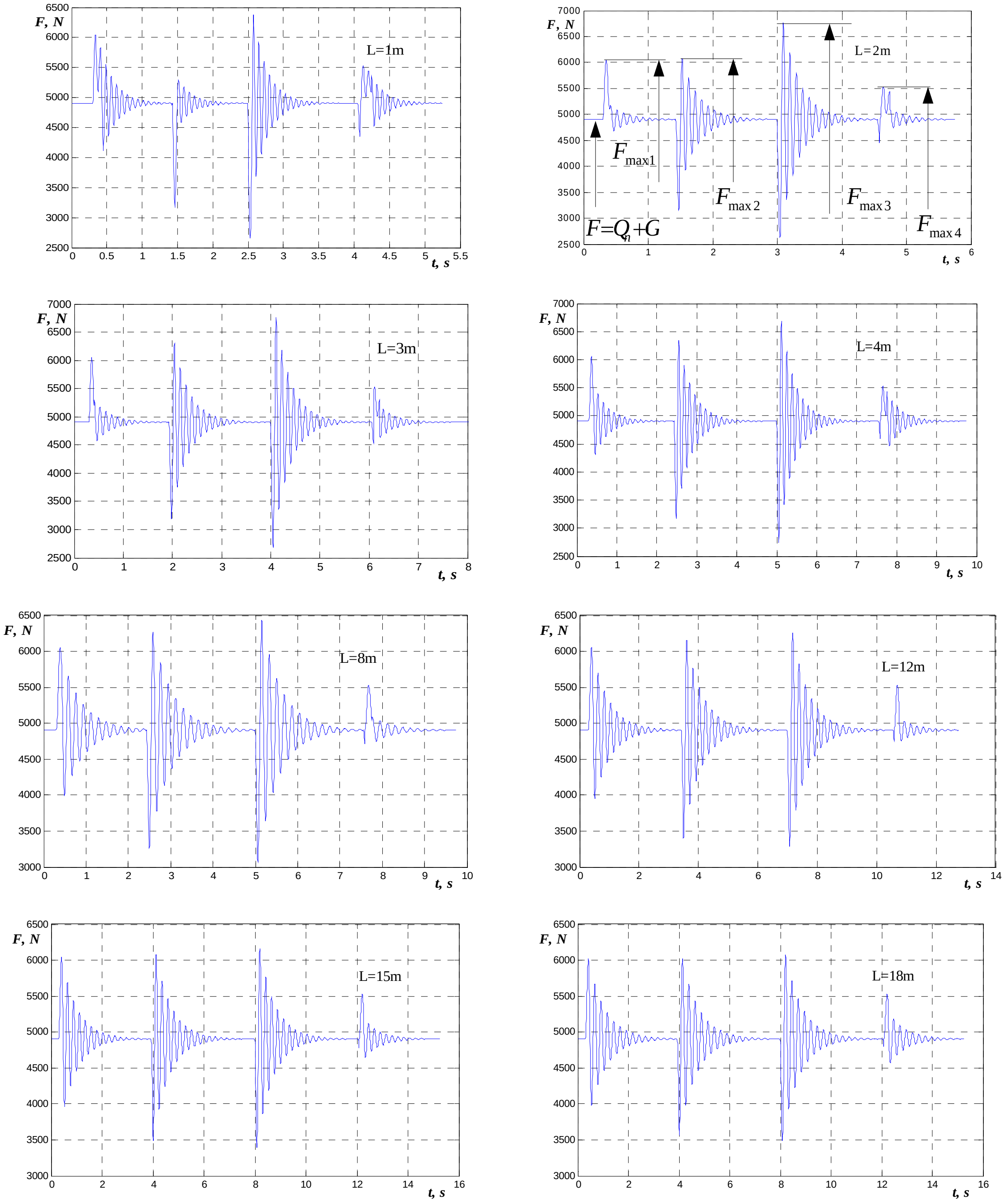


Figure 1. Graphical characteristics of the force *F* with operation of lifting device of electrical hoist for various rope lengths *L*

© copyright FACULTY of ENGINEERING - HUNEDOARA, ROMANIA

The reliability of the results in numerical experiments is checked with experiments carried out with studied electrical hoist at rated load operation mode. An experimental facility is used that is shown at Fig. 2 built on the base of the studied electrical hoist pos. 1, with possibility to register the changes of the force in flexible element and angular speed of the motor shaft in the starting and stopping processes.

In order to measure the rope force, a strain-gauge dynamometer pos. 4 (Fig. 2) is fixed on the top of the fixed branch of the tackle, developed by authors team [4]. The signal by the force-gauge proportional of the stain force in the rope is amplified by a strain-gauge amplified UM 131, then it is filtered by resistance unit R-L-C and is registered by light-beam pigtail oscilloscope 12LS-1.

In order to register the changes in angular speed of the motor, a tachometer 3 that is connected to the rotor shaft through compensating coupling 2 providing axial movement required for the cone brake built in the electric hoist. The angular speed converted by the tachometer into voltage is recorded by the pigtail oscilloscope 12LS-1.

Experiments are carried out with lifting and lowering of rated load, repeated 5 times at rope lengths L=2÷8 m. On the Fig. 3 a) and b) are shown oscillographs from experiments carried out with lifting and lowering a load at rope lengths $L \approx 4$ *m*. On the oscillographs there are registered synchronized records from the strain-gauge weighting device and from the tachometer respectively the signals 2 and 1 as well as vertical time marks 3 per 0.01 s that the oscilloscope generates.

The force $\overline{F}_{\max i}$ corresponds to the maximum rope force for the transitional process “I” and the indexes i=1, 2, 3, 4 is for the same transitional processes as in the oscillographs on Fig. 1.

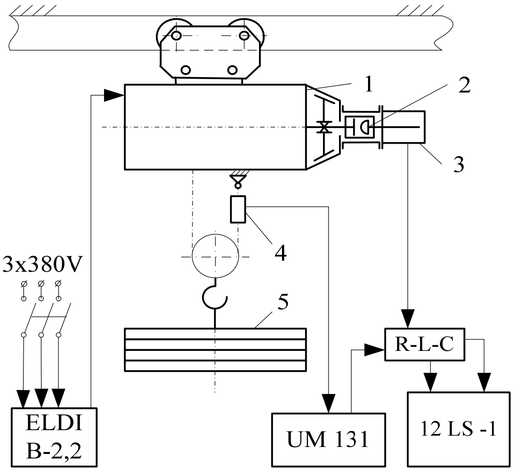
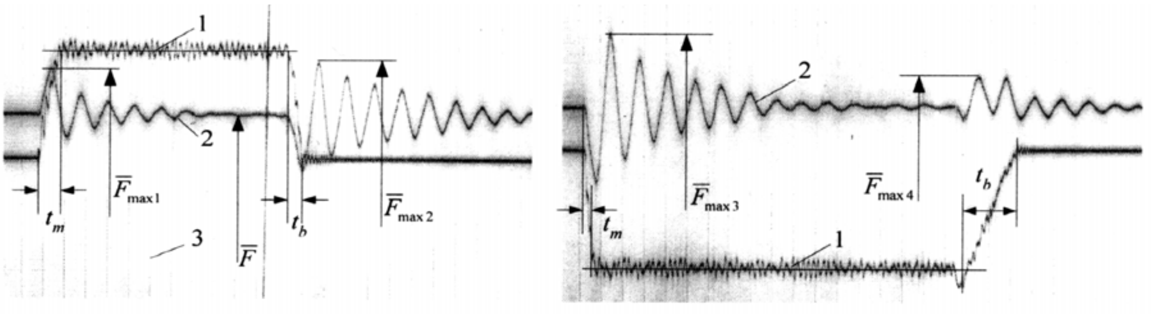


Figure 2. Experimental facility and instruments



a) b)

Figure 3. Oscillographs for the rope force and for the changes in angular speed of the motor shaft at: a) lifting suspended load; b) lowering

The maximum values of the force $F_{max,i}$ in the rope for the transitional processes of acceleration and deceleration during lifting and lowering of suspended load are calculated by the following expression:

$$F_{\max i} = k_F \overline{F}_{\max i}\,, N \tag{4}$$

where $\overline{F}_{\max i}$ is the maximum deviation of the pen calculated as an average of the five oscillographs for the respective process, mm.

k_F – the calibration factor of the stain-gauge dynamometer that is calculated by the equation

$$k_F = \frac{Q_n + G}{u_p \overline{F}}\,, N/mm, \tag{5}$$

where $\overline{F}$ is the segment proportional of the rope length in case of suspended load that is measured with the oscillograph, mm (Fig. 3).

Using the forces $F_{max,I}$ calculated according to (4) the values of the dynamic factor k_{di} are calculated for the transitional processes with $L=2 \div 8$ m by the following equation

$$k_{di} = \frac{u_p F_{\max i}}{Q_n + G}. \tag{6}$$

A comparison has been made for the values received experimentally for the dynamic factor with these for numerical experiments. The difference between the values of k_{di} from the experiments and from numerical experiments does not exceed 4% which ensures the reliability of the results received by the numerical experiments in the range of rope length L=2÷8 m.

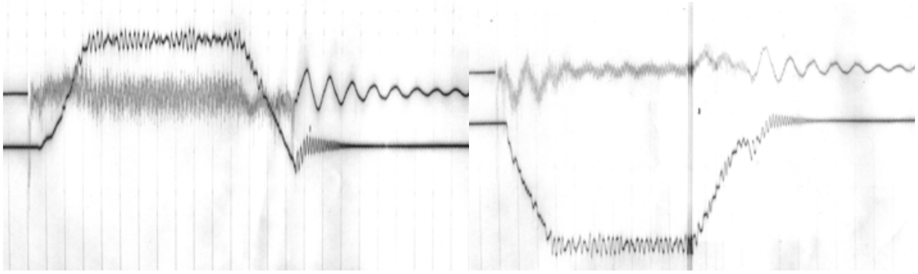

a) b)

Figure 4. Oscillographs for the rope length and for changes in the angular speed with frequency controlled motor in the processes of: a) lifting of suspended load; b) lowering of suspended load

Experiments have been carried out to determine the influence of the ratio of the times for acceleration and deceleration $t_{m(b)}$ and period T of fading oscillations of the load on the value of the dynamic loads. For that purpose the electrical hoist studied from the experimental facility of Fig. 2 is controlled by the frequency inverter ELDI B-2.2. On Fig. 4 are shown the oscillographs received for the changes of the force F and the angular speed respectively for lifting and lowering of rated load at rope length $L \approx 4$ m. In order to receive minimum dynamic forces the rimes for acceleration and deceleration $t_m = t_b = 0{,}26\text{s} \approx 2T$ are set by the inverter and the value of the fading oscillations period $T = 0{,}129$ s is calculated from the numerical experiment (Table 1). From Fig. 4 it is clear that the maximum values of the forces generated in the rope and fading oscillations in the acceleration process have several times lower amplitude compared with these received with the same rope length and the original drive shown on Fig. 3. The characteristics of the forces generated in the electrodynamic deceleration are analogous, before braking.

3. CONCLUSIONS

1. In operation with rated loads, the lifting device of the electrical hoist is subjected of high dynamic loads with small rope lengths.
2. Highest dynamic loads are generated in the acceleration during lowering of the load when the rope length is L=2÷3 m and the dynamic factor reaches value of k_d = 1,375.
3. The results from numerical experiments are reliable in the range of L=2÷8 m and can be used to determine the times of transitional processes depending on the lifting height where the dynamic loads of the lifting device have minimum values.
4. The developed methods can be used to realize a system for control of the times of transitional processes in order to reduce the force load of the components of lifting devices and metal structure.

BIBLIOGRAPHY

[1] *Iacov, W., A. Wasilev, E. Kuzmanov, I. Brayanov. Method of Adjustment of Timing Relay in "Star/delta" Starters. Scientific Works, University of Ruse "Angel Kanchev", Ruse, 2008, volume 47, series 3.1, p. 200 – 204.*

[2] *Stoyanov, B., S. Petkov, N. Mitev. Dynamic load study of electrical chain hoist at working state of traveling mechanism. Varna, Mechanics of Machines, 2006, p.134-137.*

[3] *Uzunov, T. Experimental determination of dynamic characteristics of electric wire rope hoist. under print.*

[4] *Uzunov T., G. Kenarov. Experimental investigation of dynamic load of lifting device of frequency controlled electrical motor hoist. Scientific Works, University of Ruse "Angel Kanchev", Ruse, 2008, volume 47, series 1.2, p. 63 – 68.*

[5] *Uzunov, T., S. Stoykov, G. Kenarov. Investigation methods of the influence of the times in transitional processes on the dynamic load for lifting device, under print.*

© copyright FACULTY of ENGINEERING - HUNEDOARA, ROMANIA