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Determination of the most influential factor during the rope winding process around winch drums using Taguchi method

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Abstract: *Determination of the most influential factor in the rope winding process around a winch drum is of the greatest importance for the further consideration of this process. This is performed by using the Taguchi method. The main goal function has been taken from the author's previous work. Three influential parameters have been used: friction coefficient, winding angle and pulling force. The method is performed by L4 orthogonal matrix. This paper concludes with the discussion and future research guidelines.*

Keywords: *friction, winch drum, winding, orthogonal matrices, Taguchi method.*

1. Introduction

A lot of progress in the boat equipment industry is enabled by modern technological achievements. Boat winches, as a basic part of boat equipment, also are largely developed. Gross measurements are decreased compared to used power, their efficiency is increased using various types of compact mechanical transmissions and powering aggregates. Winding capacities of cable for all types of uses on boats, from oceanographic exploration on the ocean floor, to fishing of all types of sea fish.

A lot of research has been done on boat winches: increasing efficiency, decreasing gross dimensions, decreasing total mass, improvement of powering drives by decreasing size and the power they use, improvement of winch drums for spooling cable as a rudimental winch element, improving systems of spooling, developing and research of various types of cable for different uses, as well as their properties during spooling, etc. [1].

Decreasing gross dimensions and increasing efficiency of a winch is mainly achieved by implementing compact mechanical transmissions, speed reducers. Usually with increasing compactness of the structure of a boat winch use single, dual, or multiple power inputs. Also a frequent use of planetary reducers due to the possibility of their installation into the winch drum.

A lot of attention is dedicated to testing and developing of cables which are used on winches. For boat winches steel is the most frequently used material, while much less synthetic cables are used. Oceanographic winches usually use various types of cables instead of cables, for transmitting data from testing devices in the ocean to the boat. With developing new types of steel cables a lot of attention is given to external forces of tension and torsion which influence the cable, as well as inner friction forces which appear between the cable wires, [2-6].

Work on improving winch drums, as a rudimental element of a winch is based on testing the influence of forces on the winch drum, using experimental and finite element methods, [7]. Improvement of drums is done by decreasing thicknesses of the material in the non-critical areas of the drum, while the critical areas are made thicker, also stiffeners are implemented where needed, [8].

Improvement of systems for guiding proper cable spooling onto the boat winch is based on its quality of synchronization with the revolution speed of the winch drum. Synchronization of boat winch revolutions and the system for proper spooling can be achieved by various methods. Some of the methods are mechanical synchronization using a chain drive or placing an additional power drive for this system which is synchronized with the primary winch drum spooling motor.

Determining of influence parameters which are important for the process of spooling is of great importance so that the process can flow without failure. Taguchi method represents the best choice for determining influence parameters on the process of spooling, [9-12]. After determining and grading parameters, which influence the spooling process by influence, it is possible to determine errors which appear in this process ahead of time and remove them.

This paper gives an explanation of how the Taguchi method works and its use in the equation which defines the process of spooling [13]. The paper closes with derived conclusions and given directions for further research in this field.

2. Field of use and functioning of Taguchi method

Use of Taguchi method and Taguchi techniques is widely spread in all branches of engineering, therefore also in other fields of study. Uses of Taguchi method are as follows:

- Use of method for designing experiments,

- Use of method for quality control,
- Use of method for robust design,
- Use of method for panning production,
- Use of method for economical analysis,
- Use of method for marketing, etc.

Using these methods a drastic improvement in quality control can be achieved as well as product quality. The biggest advantage of the use of this methodology on numerous processes is, that at the end of the method the influence of each factor which influences the process is attained.

Taguchi method in its essence functions as other optimization methods. The Taguchi method also has a goal function and input parameters as well as conditional functions. A block diagram of the method is shown in figure 1.

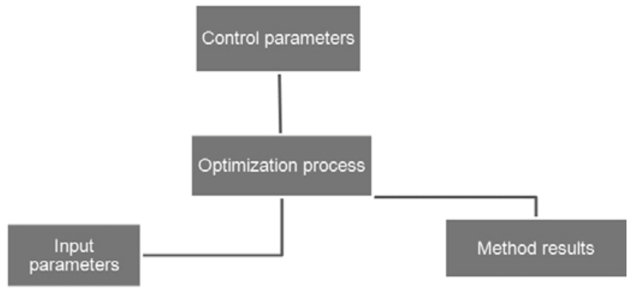

Figure 1 Taguchi method diagram

Steps in using Taguchi method are as follows:

1. Defining goal function *f(X)*. Goal function can be any variable. Depending on weather a minimum or maximum function mathematical formulas for calculation the minimum or maximum are chosen,

2. Determining parameters $G(X_i)$ which influence the process which is being optimized. These are parameters which are variably controlled by the Taguchi method level. More levels allow greater parameter variations,

3. Choice of original matrix for conducting Taguchi method. Depending on the number of influencing parameters on the process an orthogonal matrix is chosen according to which the Taguchi method is used,

4. Conducting the method according to the chosen matrix. This is possible by making algorithms or calculation programs, or in some software which supports Taguchi method (i.e. Minitab)

5. Discussions of results and ranking of parameters which influence the process.

From the described steps it can be seen that the final results of the Taguchi method is not a numeric value of optimal parameters, but a value of its influence on the process which is being optimized. It can also be seen that the Taguchi method has a use in finding maximal and minimal goal function *f(X)*.

3. Use of Taguchi method on the spooling process of the cable onto the winch drum

This process is especially good for use of Taguchi method, since it uses a small number of variables. Data for the use of Taguchi method are taken from previous work of the author. [13].

3.1 Setting a goal function

For the goal function dependence of friction force changes between cables during spooling of the cable onto the winch drum from the pulling force is chosen, angle of spooling and coefficients of friction between cables. Goal function is given in equation (1):

$$F_{\mu} = F_{W}\left(1 - \frac{1}{e^{\mu\varphi}}\right) \tag{1}$$

Using the Taguchi method will determine specific influence parameters of the pulling force F_W, spooling angle φ, and friction coefficient between cables μ, on changing friction force intensity F_{μ}.

3.2 Defining influential parameters on the spooling process

With this problem there are three parameters whose change directly influence the goal function, force Fμ, and those are:

- Pulling force F_W,
- Friction coefficient μ,
- Spooling angle φ.

For each of these problems variations which are taken from the author's previous work are defined [13]. Variable variation parameters for specific measurements are:

- Variation of pulling force F_W, which appears as a result of pulling the net through water, it is around ± 2,5 % to the initial pulling force.
- Variation of friction coefficient μ, which appears as a result of irregularities between cable layers during spooling, it is around ± 0,05 % to the initial friction coefficient.

- Variation of spooling angle due to circular motion of the winch drum which spans to $\varphi=0$ to the end of cable spooling.

Size of angle φ depends on the length of spooled cable.

In order to determine the influence of specific parameters which influence on friction force using Taguchi method it is enough to have the angle φ change by a small value, as well as other parameters too. For solving this problem two positions are considered in the change of angle φ:

φ_1 = 100[$\varphi\approx$0,175 rad] and

φ_2 = 200[$\varphi\approx$0,350 rad].

Initial friction coefficient is μ = 0,25, while the varied coefficients which are closer to real conditions are:

μ_1 = 0,245 and

μ_2 = 0,255.

Initial pulling force is F_W = 2452 [N], while its varied values which are closer to real conditions are:

F_{W1} = 2513 [N] and

F_{W2} = 2391 [N].

These experimental values can be placed in table 1 for better overview.

Table 1 Simulation data which determines the goal function

Spooling angle φ [rad]		Friction coefficient μ		Pulling force F_W [N]	
φ_1	0,175	μ_1	0,245	F_{W1}	2513
φ_2	0,350	μ_2	0,255	F_{W2}	2391

3.3 Choice of orthogonal matrix

Based on the number of parameters chosen is orthogonal matrix L4. Table 2 shows the variation of parameters in matrix L4.

Table 2 L4 orthogonal matrix

Test No.	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$
1.	1	1	1
2.	1	2	2
3.	2	1	2
4.	2	2	1

The order of ones and twos in the orthogonal matrix L4 signifies the order of experimental parameters in table1, and the way their variation is done using the goal function. For these three parameters and their values there will be a total of four tests in two iterations. Iterations of tests depend on the level of Taguchi method. Matrix L4 for example represents a matrix with three parameters which are iterated in two levels. However, iterating goal functions dont have to necessarily be on an equal level of Taguchi method, but they must be at least minimally equal to the number of the chosen matrix level. For this experiment two iterations of the goal function will suffice.

3.4 Use of Taguchi method

Choice of matrix and use of parameters for using Taguchi method accounts for a greater part of the method use. After preparation, an extended table is formed with calculated goal functions (Table 3).

Table 3 Extended table with calculated goal functions

Test No.	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$	$T_1 = F_\mu$	$T_2 = F_\mu$
1.	0.245	0.175	2513	102	201
2.	0.245	0.35	2391	106	208
3.	0.255	0.175	2391	109	199
4.	0.255	0.35	2513	104	210

After calculating columns T1 and T2 using the goal function calculating S/N ratio is next. For this example S/N is calculated according to the general function, since it is not specified weather the minimal or maximal goal function is required, but the influence of parameters on the general phenomenon:

$$S/N_i = 10\log\frac{\overline{T}_i^2}{s_i^2} \qquad (2)$$

Calculate the S/N ratio with other parameters given in table 4:

Table 4 S/N ratio

Test No.	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$	$T_1 = F_\mu$	$T_2 = F_\mu$	S/N
1.	0.245	0.175	2513	102	201	6.22
2.	0.245	0.35	2391	106	208	6.27
3.	0.255	0.175	2391	109	199	7.29
4.	0.255	0.35	2513	104	210	5.90

After all calculations of goal functions and S/N ratio for easier use of formulas for filling in the final matrix for tanking parameters it is recommended that the S/N ratio is returned to the initial table L4. This operation is shown in table 5.

Table 5 Table of modes of parameter variation extended with S/N ratio

Test No.	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$	*S/N*
1.	1	1	1	6.22
2.	1	2	2	6.27
3.	2	1	2	7.29
4.	2	2	1	5.90

3.5 Ranking parameters by influence on the process of spooling

The last operation to determining the influence of variables on the goal function is filling in the final matrix and drawing the S/N diagram. Calculating members of the final matrix is done by equations (3):

$$S/N_{P3,1} = \frac{(S_{N1} + S_{N6} + S_{N8})}{3}$$
$$S/N_{P3,2} = \frac{(S_{N2} + S_{N4} + S_{N9})}{3} \quad (3)$$
$$S/N_{P3,3} = \frac{(S_{N3} + S_{N5} + S_{N7})}{3}$$

Filling in the final matrix with all calculated members is given in table 6:

Table 6 Final matrix L4

Level	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$
1	6.24	6.75	6.06
2	6.59	6.08	6.78

Ranking parameters by influence is done using equation (4):

$$R_{Pi} = \max(Pi) - \min(Pi) \quad (4)$$

Ranking of parameters is shown in table 7:

Table 7 Ranking of parameters

Level	$P_1 = \mu$	$P_2 = \varphi$	$P_3 = F_W$
1	6.24	6.75	6.06
2	6.59	6.08	6.78
Δ	0.35	0.67	0.72
Rang	3	2	1

From table 7 it can be seen that the greatest influence on the pulling friction force during spooling of the cable on the winch drum is from pulling force F_W, while the second most influential parameter is the angle of spooling φ, while the least influential is the coefficient of friction μ between the cables. Figure 2 shows the influence of specific parameters on the friction force intensity between cables during spooling onto the winch drum.

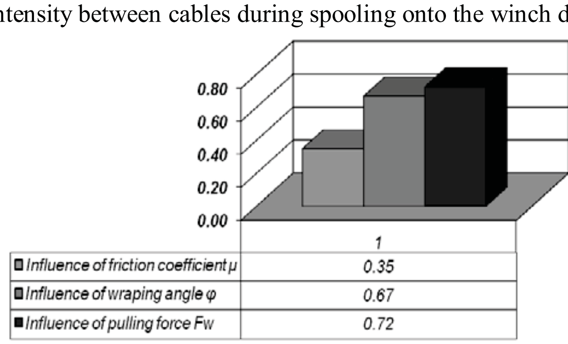

Figure 2 Parameter ranking

4. Conclusions

Mathematical model, which is created in previous author's papers [1,13], is used for determination of parameters significance of cable spooling process on the winch drum. In the mathematical model of cable spooling process on the winch drum influent parameters are: puling force, cable spooling angle and friction coefficient between cables.

The most influential parameter in this process is pulling force F_W, which is shown in the Figure 2. Cable spooling angle φ is second most influential parameter in this process, and it is lesser by about 7% than the influence of pulling force. Influence of friction coefficient between cables is third influential parameter and it is lesser by about 51% than influence of pulling force.

Future research on this topic will be oriented on perfecting of the mathematical model of this process, as on experimental examination of results.

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