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THE SOLUTION OF SEARCHING TASK OF AN OPTIMUM DESIGN OF LOAD-LIFTING WINCHES USING THE PARETO PRINCIPLE

Roman Anatolyevich Kobzev and Natalya Mikhaelovna Chernova
National Research Nuclear University MEPhI, Moscow, Russian Federation
E-Mail: dmitry.shkurkin@gmail.com

ABSTRACT

In this paper the question of searching of a load-lifting winches optimum design is considered. The method of optimum design is chosen. The original algorithm of searching of optimum solution has been offered. It is offered to consider a problem of optimum design of load-lifting mechanisms as a problem of multi-criteria optimization. For the solution of this task use is recommended optimization method based on the Pareto principle. Load-lifting winch was represented as complicated system which includes several subsystems in the course of search of the optimal solution. Between these subsystems exists the interaction interference. For this reason the tasks of subsystem optimization can't be solved in parallel. The algorithm has been offered for searching of optimum solution. It's based on application of the method of dynamic programming. The offered approach gives the chance to receive the designs which are optimum by any in advance chosen criteria.

Keywords: lifting facilities, load-lifting winches, optimal design, pareto principle, method, dynamic programming.

1. INTRODUCTION

The integral part of any industrial enterprise is lifting facility. This helps to carry out the main part hoisting-and-transport and loading-and-unloading operations in the shops and outside. The key elements of any lifting facilities are load-lifting winches or lifting mechanisms. With their help movement of freight in the vertical plane is directly carried out. The choice of an optimum design of load-lifting winches is improves technical-and-economic index not only of the winch, but also the mechanisms which are carrying out movement of freight in the horizontal plane and carrying iron of lifting facilities.

2. THE MATERIALS AND RESEARCH METHODS

There are many researches of the hoisting machine optimum design which is carried out by the scientists of various countries of the world [1 - 4]. The best solution is chosen based on the comparison options by criterion of minimum total discounted costs, mass or manufacturing cost in most cases. In this case the optimization objective is one-criteria and it can be solved easily. However in practice there are requirements to a design of the hoisting machines and the load-lifting winches. Some of them are contradictory. For example, increase in level of the car safety will inevitably lead to increase in its cost. The assigned task should be considered as multi-criteria for which solution it is necessary to apply methods of multi-criteria optimization.

The most widespread tool of the solution of multi-criteria tasks is the Pareto principle including the field of various technical systems optimization [5 - 7]. In all the considered options has to be provided performance of the part of requirements which was produced to the hoisting machines design and which was entered as restrictions imposed on area of possible decisions. The requirements which may be made concessions for best results for other requirements are the optimization criteria. The right choice of optimization criteria is complicated task and deserves separate consideration. But advantage of the Pareto principle using is the possibility of introducing unlimited quantity of criteria as a part of the vector quality criterion. A part of the vector quality criterion should be determined by the decision-maker based on the product requirements document in each case.

The essence of the Pareto principle is existence of solution set $P_f(X)$ among all possible solutions of mechanism X between which decision-maker can't express a clear preference. It is called Pareto-optimal solutions set or Pareto set. Any Pareto-optimal solution surpasses to another by many criteria but concedes at least to one another. At the same time each Pareto-optimal solution concedes any other solution which it isn't included by all criteria in Pareto set.

Mathematically Pareto set (Pareto-optimal solutions set) can be determined by the expression:

$$P_f(X) = \{x^* \in X, \text{ there is no such } x \in X, \text{ that } x \prec x^*\},$$

where X – set of possible solutions, x – solution vector, x^* – Pareto-optimal solution vector in multi-criteria space, $\prec$ – preference ratio.

The vector quality criterion is used to establish the preference between individual solutions:

$f(x) = (f_1(x),\ f_2(x),\dots f_m(x))$,

where $f_1(x), f_2(x),\dots f_m(x)$ – solution valuations x by private criteria of multicriteria m- dimensional space R_m, also called components of the vector quality criterion, $f(x)$ – general vector valuation of solution x.

It's considered that $x \prec x^*$ if $f(x) \geq f(x^*)$, that is to say it's inequality system:

$$\begin{cases} f_1(x) \geq f_1(x^*) \\ f_2(x) \geq f_2(x^*) \\ ... \\ f_m(x) \geq f_m(x^*). \end{cases}$$

Not for any pair of solutions can be establish strong preference as seen from this expression. In this case, for example, impossible to establish preference between two Pareto-optimal solutions because one solution must be removed from Pareto set.

In this way, the formation of Pareto set $P_f(X)$ can be carried out by comparison of vector evaluations of individual solutions between itselves using the vector quality criterion $f(x)$ and exclusion of solutions which concedes to any other solution. Further, among the solutions included in the set $P_f(X)$ decision-maker must make the final decision. If Pareto set $P_f(X)$ is too wide for conscious choice of the decision-maker necessary to make supplementary set constriction $P_f(X)$. Solutions set obtained after Pareto set constriction $P_f(X)$ and denoted $Sel(X)$ and called selected solutions set.

Different Pareto set constriction methods apply for the formation of selected solutions set $Sel(X)$. The multi-criteria task is reduced to one-criteria in the majority from them. It means that the objective function includes all criteria (which included in the vector quality criterion $f(x)$) is defined. For example, it can be in the form of linear convolution with introduction of the weight coefficients which reflect importance each of the criteria

$$T = \sum_{i=1}^{m} \lambda_i f_i(x),$$

where λ_i – weight coefficient of significance criterion $f_i(x)$, i – criterion number.

Weight coefficients can be determined by the decision-maker in advance in the simplest case. In other methods its values are defined analytically based on comparison of some Pareto-optimal solution selection by the decision-maker [8, 9]. Values of each weight coefficient are defined in the analysis of the preferences between decisions and their estimates received when comparing by various criteria in number $f_i(x)$.

With regard to the task in some cases it is difficult to define degree of the importance of each of criteria. Often the importance of the same criterion can change and depend on other parameters. It means that there isn't always an opportunity to set values of weight coefficients initially. The person can have an opportunity to establish preferences between separate decisions (second approach). In this case the best solution can be manual determine by the decision-maker for rather narrow Pareto-optimal solutions set. If total set will be too big manual determining it is necessary to use method which is described in [8, 9].

Generally the search task of optimum solution for load-lifting winch includes two stages: the search of optimum block diagram and the choice of optimum parameters of separate individual elements included in its composition. It's impossible to develop a single universal algorithm which can carry out the decisions of these two problems at the same time in the automatic mode because the block diagrams of load-lifting winches are various. Therefore it is offered to carry out manual determining of the most perspective block diagrams by the decision-maker at a preliminary stage. After that it is possible to form Pareto-optimal solutions set for each of diagrams. Further having united everything received Pareto-optimal solutions in general set and again comparing them with each other Pareto-optimal solution can be received for all considered block diagrams.

Load-lifting winch was represented as complicated system which includes several subsystems in the course of search of the optimal solution. In the most general option block diagram structure of load-lifting winch includes the following subsystems of modules: electric motor and control system, the block and tackle and load-grappling device, the module of the load drum setting, the transmission module which include the reducer and connecting couplings, the open gear train module, the brake (or brakes) module. Some of the listed modules are the part of very limited number of block diagrams. In particular the open gear train module seldom meets. Often some modules can be integrated among themselves. For example, electric motor may include imbedded brake module. The motors reducers are widely applied. It's impossible to design the general algorithm of search for all possible schemes because of this variety of block diagrams.

The simplest approach to the solution of an optimization problem of complicated systems which includes several subsystems is search of optimal solutions for each subsystems. Further the common optimal solution will be received as optimal solutions set which are received for each subsystem. However similar approach is inapplicable for task of load-lifting winches optimum design because there are interrelations between subsystems. Whereupon the solutions made for one subsystem have influence on area of possible solutions of other subsystem. The most striking example of similar interrelation is the providing condition of ensuring lifting speed of loads which determined by the product requirements document. The chosen decisions for the tackle multiplicity u_{bt} or load drum diameter D_d are impose restrictions for possible values of nominal frequency of electric motor rotation n_{mot} and transfer transmission relations u_{tr}. In addition it is necessary to consider restrictions imposed on conditions of assembly of separate subsystems among themselves. Due to noted features of the considered task in search algorithm of optimum solution it has been proposed to use method of dynamic programming which was widely used at the decision of the optimizing tasks [10 - 12].

The databases of possible solutions previously forms for each module which is available in the scheme.

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The optimum design task is a reception of the partial solutions combination for individual modules which will provide the best estimate for the vector quality criterion if all the restrictions which superimposed on the overall system and its subsystems in particular

Lifting speed load v is determined by the following parameters: already mentioned above n_{mot}, $D_{d,}$ u_{tr}, u_{bt} and transfer ratio of open gear train u_{ogt}. It's impossible to carry out a redistribution of values between the individual modules because these options have a different dimension. Therefore, we introduce a new parameter υ, which is called the degree of reduction. The degree of reduction can be defined as the entire system and to individual modules.

The degree of reduction of the winch can be determined as:

$$\upsilon = \frac{n_{mot\,\max} \cdot \pi \cdot D_{d\,\max}}{u_{bt\,\min} \cdot u_{r\,\min} \cdot u_{ogt\,\min} \cdot v},$$

where $n_{\mathrm{mot}\ max}$ – maximum speed of the motor for all the available motors in the database, $D_{d\,\max}$ – maximum drum diameter for all the available drums in the database (given previously by decision-maker individually for each crane), $u_{bt\,\min}$, $u_{r\,\min}$, $u_{ogt\,\min}$ – minimum all the available block and tackle multiplicities ($u_{bt\,\min} = 1$), transfer reduction ratios and open gear train ($u_{ogt\,\min} = 1$).

The degree of each modules reduction for separate decisions will be defined as follows:
for the module of the electric motor and a control system:

$$\upsilon_{1f} = \frac{n_{mot\,\max}}{n_{mot\,f}};$$

for the module of block and tackle and load-grappling device:

$$\upsilon_{2f} = \frac{u_{bt\,f}}{u_{bt\,\min}};$$

for the module of the load drum setting:

$$\upsilon_{3f} = \frac{D_{d\,\max}}{D_{d\,f}};$$

for the transmission module:

$$\upsilon_{4f} = \frac{u_{r\,f}}{u_{r\,\min}};$$

for the open gear train module:

$$\upsilon_{5f} = \frac{u_{ogt\,f}}{u_{ogt\,\min}};$$

where $n_{mot\,f}$, $u_{bt\,f}$, $D_{d\,f}$, $u_{r\,f}$, $u_{ogt\,f}$ – engine speed, block and tackle multiplicity, drum diameter, transfer numbers of reduction and open gear train for для some f-th solution respectively, f – number of solution in the database for the corresponding module.

The actual degree of reduction for the entire system is generally determined by the expression:

$$\upsilon = \upsilon_{1f} \cdot \upsilon_{2f} \cdot \upsilon_{3f} \cdot \upsilon_{4f} \cdot \upsilon_{5f}.$$

The general search algorithm of optimum solution using method of dynamic programming. It's looks as follows. Pareto-optimal solutions set will be previously formed for each of the modules separate for the each degree of reduction. Further will be made general Pareto-optimal solutions set for the first two modules for the all received degrees of reduction based on method of dynamic programming. All the conditions which superimposed on the reviewed modules is checked at the same time. Further, considering combinations of received general Pareto-optimal solutions for the first two modules with particular Pareto-optimal solutions for the third module general Pareto-optimal solutions set is formed for the first three modules also for all the reduction degrees received at the same time. After repetition of similar procedure for the remained modules Pareto-optimal solutions set will be received for complete system within the considered block diagram on the last step. At the same time conditions are checked. These restrictions are imposed on the last module and on all systems of the mechanism in general. At this stage all solutions will have the general degree of reduction which is determined according to mechanism speed. It's determined by the product requirements document. In the next step general Pareto-optimal solutions which received for different kinematic schemes on similar algorithm are compared. As a result Pareto-optimal solutions set for lifting mechanism finally formed. The decision-maker will make a manual optimum solution if received set will be rather narrow. Otherwise Pareto set constriction method which is described in [8, 9] will be used.

3. CONCLUSIONS AND DISCUSSIONS

The offered search method of optimum solution for load-lifting winches allows to allocate the number of Pareto-optimal solutions of an infinite number of different possible solutions. These solutions are the best of for pre-selected set of optimality criteria. The method can be used the crane-building enterprises and development design offices the design of new structures of hoisting winches and cranes. The advantage of the proposed method is ease of it's algorithmization and realization in the form of the software product. The disadvantage is need of labor-consuming formation of the private possible solutions database for the separate modules. At the same time it should be noted that if to create once similar base it can be reused at the solution of new design tasks

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