# Innovative Methods in Control of Processes and Algorithms of their Implementation

S. Aliukov, L. Shefer, R. Gubbe, and I. Khaidrashin

*Abstract*— **In this article methods of process control on the basis of modern approaches and the theory of fuzzy sets are considered on the example of controlling electric drives of hoisting-and-transport mechanisms, in particular, container cranes. The most urgent tasks in this area are the problems associated with limiting vibrations of cargo during its transportation. According to statistics, more than a quarter of the allotted time for one complete cycle of loading and unloading works is spent on damping the vibration movements of the cargo, which leads to economic losses throughout the entire technological process. In addition, the vibration load leads to an increase in the dynamic load on the electric drive and the design of the crane as a whole. In the article algorithms of implementation of modern laws governing the electric drives of hoisting-and-transport mechanisms are considered, thanks to which the most efficient way of cargo transportation is achieved. This leads to a significant improvement in the technical and economic indicators of the technological process. The variants of automation of the process of controlling hoisting and transport mechanisms on the basis of exact mathematical dependencies and on the basis of the theory of fuzzy sets are considered. As a rule, when using fuzzy modeling methods for optimal control of container cranes, only two input parameters are considered: moving the trolley and the angle of deflection of the cable of the container from the vertical. Meanwhile, the important component is the strength of the wind. When optimizing the control of the crane, it is undoubtedly necessary to take into account this characteristic. The algorithm of the process of container crane control taking into account the wind characteristic is proposed in this paper. It is shown that the application of methods of fuzzy modeling can dramatically reduce costs in the design of hoisting-and-transport mechanisms.**

***Index Terms***— **Hoisting-and-transport mechanisms, control laws, optimization, fuzzy sets**

## I. Introduction

HOISTING-AND-TRANSPORT mechanisms are used everywhere [1-5], for example, in machine building at various plants for the production of pipes, steel, concrete, glass, reinforcement, frame houses, etc. The relevance of the topic on improving the technological process associated with the transportation of goods through the use of various hoisting-and-transport mechanisms is the most in demand in all areas of their application. To improve and optimize the technological process of hoisting-and-transport mechanisms designers use the laws governing the electric drives and methods of the theory of fuzzy sets. The paper considers an effective method of controlling electric drives of hoisting and transport mechanisms, which allow reducing the monetary costs for its implementation to a minimum. An unequivocal advantage of this method of controlling hoisting-and-transport mechanisms is the lack of the need to purchase and further service additional expensive equipment. Let's consider the possibilities of improving the management algorithm for container gantry cranes. One of the most important features of container gantry cranes is the ability to cover large reloading and storage areas along which access roads of different types of transport are laid, for example, automobile and railway ones. Cranes of this type are mainly used in terminals with large cargo turnover and the rate of processing of containers of rail, road, sea, river, as well as container sites of industrial enterprises and warehouses.

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## II. The Process of Controlling Electric Drives of Hoisting-and-Transport Mechanisms

A crane is designed for lifting and moving loads during construction, assembly, repair, loading and unloading and other works [6]. The crane is a load-lifting machine of cyclic action. Schematic device of the system "container crane - container - purpose" is shown in Fig.1.

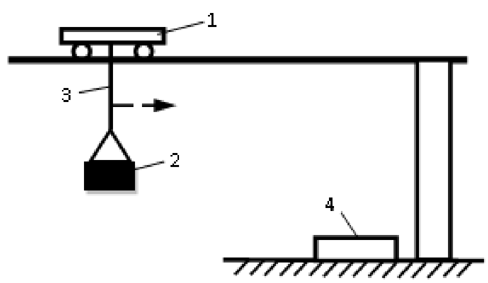


Fig.1. System "container crane - container - purpose"

The container crane 1 is connected to the monoblock container 2 by a flexible cable 3 and lifts the container to the crane cabin. The crane cabin together with the container can be moved horizontally along rail-type rails. When the container raises to the crane cabin, and the cabin

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comes into motion, the container starts to swing and deviate from the strictly vertical position under the crane cabin. The problem is that as long as the container is swayed during its transportation and deviates from the vertical, it can not be lowered to the base of the transfer target 4, which uses railroad platforms or other vehicles.

In our fuzzy model, we use three input linguistic variables and one output.

The variable "Angle" is the first input variable. The range of this variable varies from $-90^{o}$ to $+90^{o}$. The term-set for this variable is the set with the following elements: very negative, negative, zero, positive, very positive. The graphs of the membership functions of the terms for this variable are shown in Fig.2.

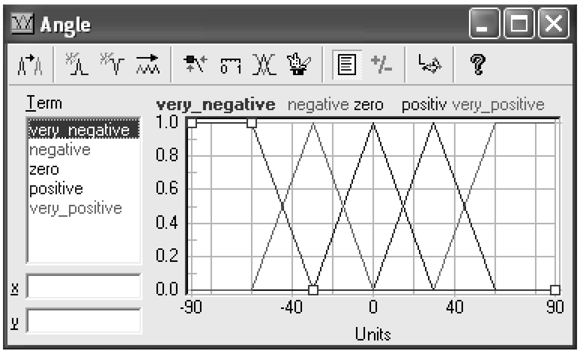


Fig.2. Term-set for the variable "Angle"

The second input linguistic variable is "Distance". The range of this variable varies from 0 to 50 m. The term-set for this variable is the set with the following elements: zero, close, medium close, medium far, far. The origin point is in the initial location of the cargo. The graphs of the membership functions of the terms for this variable are shown in Fig.3.

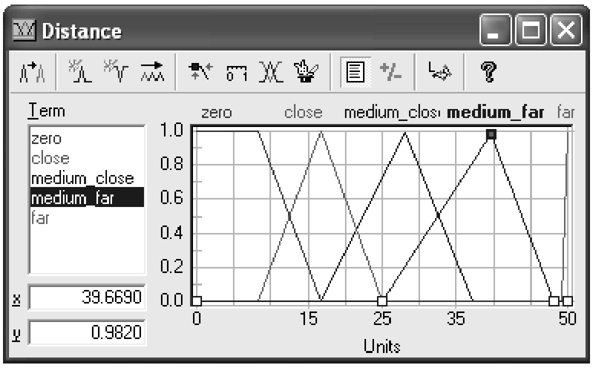


Fig.3. Term-set for the variable "Distance"

The third input linguistic variable is "Wind". The range of this variable varies from 0 to 30 m/s. The term-set for this variable is the set with the following elements: very small, small, medium, large, very large. The graphs of the membership functions of the terms for this variable are shown in Fig.4.

When constructing the term set, the Beaufort's wind force scale was taken as a basis [7]. This scale is shown in Table.

As the output variable we use the linguistic variable "Power" with a range from -30 kW to 30 kW. The term-set for this variable is the set with the following elements: very negative, negative, zero, positive, very positive. The graphs of the membership functions of the terms for this variable are shown in Fig.5.

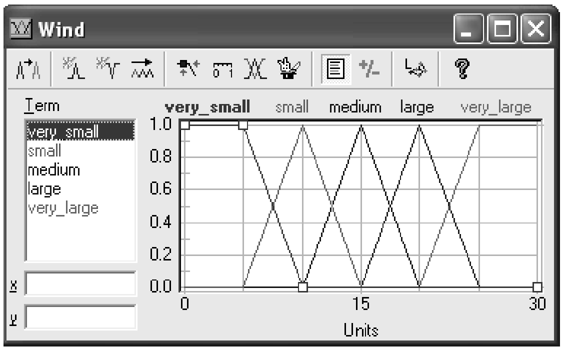


Fig.4. Term-set for the variable "Wind"

Table: The Beaufort's wind force scale

| **Description** | **Wind speed, m/s** |
|---|---|
| Calm | < 0.3 |
| Light air | 0.3–1.5 |
| Light breeze | 1.6–3.3 |
| Gentle breeze | 3.4–5.5 |
| Moderate breeze | 5.5–7.9 |
| Fresh breeze | 8–10.7 |
| Strong breeze | 10.8–13.8 |
| High wind, moderate gale, near gale | 13.9–17.1 |
| Gale, fresh gale | 17.2–20.7 |
| Strong/severe gale | 20.8–24.4 |
| Storm, whole gale | 24.5–28.4 |
| Violent storm | 28.5–32.6 |
| Hurricane force | ≥ 32.7 |

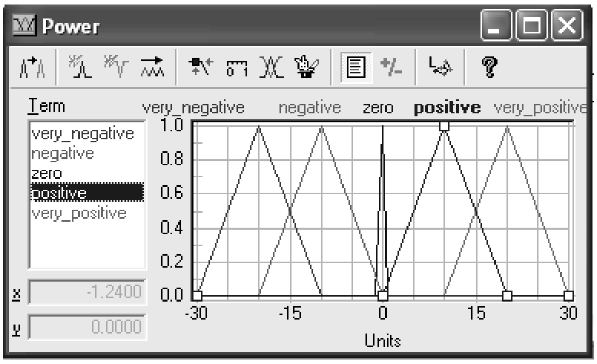


Fig.5. Term-set for the output linguistic variable "Power"

The input parameters A ("Angle"), D ("Distance") and W ("Wind") are independent (exogenous) values. The output parameter P ("Power") is a dependent (endogenous) value. In general, the model operator F converts the exogenous parameters into endogenous ones:

$$F:\{A,D,W\}\rightarrow P.$$

When forming a block of rules for the system of fuzzy inference, we took into account the significant effect of wind speed. For example, in Fig.6a and Fig.6b there are the formed rules for the values of the wind speed such as "very small" and "very large" respectively. The main idea was the following. With higher wind speeds, the process of moving the load must be performed at low speeds, which requires lower power values. For example, some of the rules are as follows:

- if "Angle" is "negative", "Distance" is "close" and "Wind" is "very small", then "Power" is "positive";
- if "Angle" is "zero", "Distance" is "medium close" and "Wind" is "very small", then "Power" is "very positive";
- if "Angle" is "very negative", "Distance" is "close" and "Wind" is "very large", then "Power" is "negative";
- if "Angle" is "zero", "Distance" is "far" and "Wind" is "very large", then "Power" is "zero";
- and so on.

a)

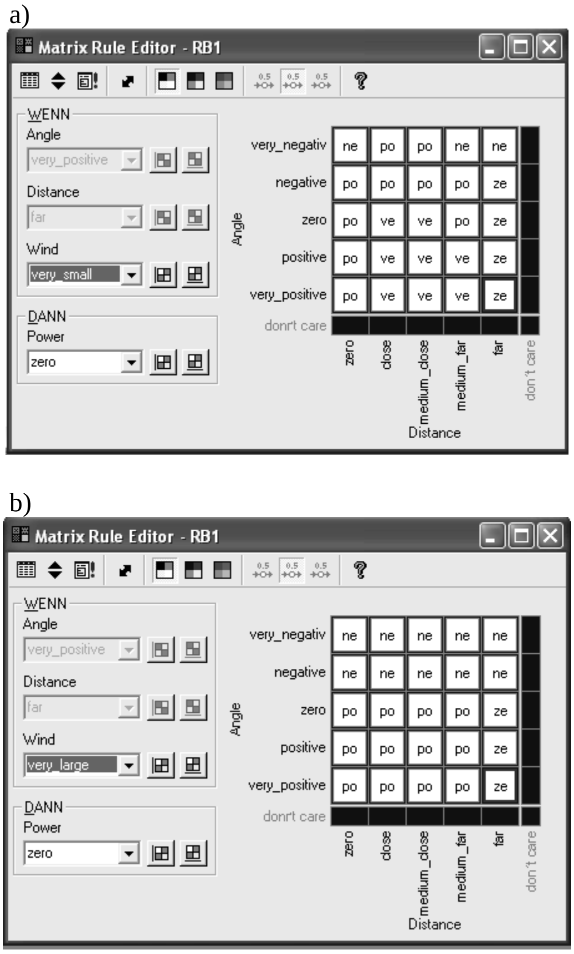


Fig.6. Blocks of rules for the different values of speed of wind: a) very small value; b) very large value

The block diagram obtained by the fuzzy modeling method is shown in Fig.7.

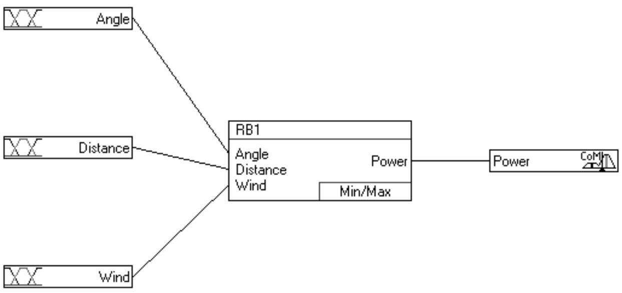


Fig.7. Diagram of the block rules

It is known [8] that almost all real working applications that use the intermediate evaluation of fuzzy systems based on fuzzy production rules. When performing fuzzy conclusions use of fuzzy relations R defined between one area (the set X) and the other area (the set Y) in the form of an odd subset of the direct product $X \times Y$, determined by the formula:

$$R = \sum_{i=1}^{n} \sum_{j=1}^{m} \left\{ \left( \mu_R \left( x_i, y_j \right) | \left( x_i, y_j \right) \right) \right\},$$

here $\left\{ x_1, x_2, ..., x_n \right\}$ is the scope of the prerequisites; $\left\{ y_1, y_2, ..., y_m \right\}$ is the scope of the conclusions; $\mu_R \left( x_i, y_j \right)$ is the membership function fuzzy relation $R$.

For production rules of type "If A, then B" using fuzzy sets A and B, one of the ways to construct fuzzy matching R is as follows:

$$R = A \times B = \sum_{i=1}^{n} \sum_{j=1}^{m} \left\{ \left( \mu_A \left( x_i \right) \wedge \mu_B \left( y_j \right) | \left( x_i, y_j \right) \right) \right\},$$

here $\mu_A \left( x_i \right)$ and $\mu_B \left( y_j \right)$ are the membership functions of the elements of x and y to the sets A and B respectively [9,10].

The constructed model allows, using the known values of input variables, with help of methods of fuzzy mathematics to logically find the resulting value of the output variable [11-14]. For example, if the "Angle" is equal 20.92 degrees, the "Distance" is equal 32.75 m, and the "Wind" is equal to 7.5 m/s, then the "Power" should be 15 kW (Fig.8a). If the "Angle" is equal -35 degrees, the "Distance" is equal 35 m, and the "Wind" is equal to 20 m/s, then the "Power" should be -7.11 kW (Fig.8b). As further calculations have shown, the values of the variable "Power "can differ significantly with the same values of the input variables "Angle" and "Distance", but different values of the input variable "Wind". This feature of the construction of the algorithm of the container crane control process, as a rule, was not taken into account in earlier studies.

a)

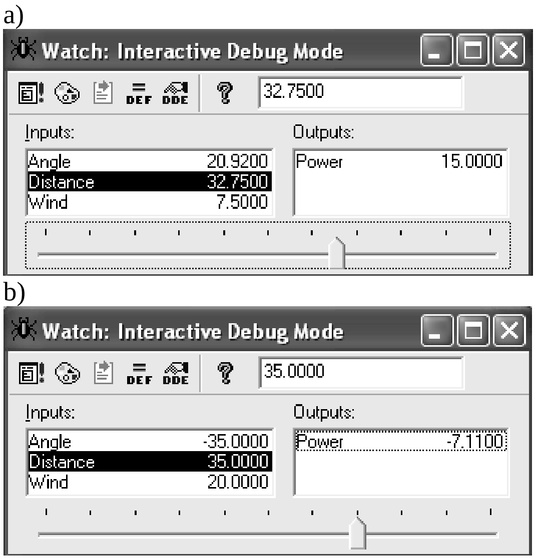


Fig.8. The value of the output variable depends on the values of the inpur variables

On the basis of the developed technology of definition of values of the output variable, the 3D plotes diagrams for the output variable "Power" were constructed depending on: a) input variables "Angle" and "Distance" (Fig.9a); b) input variables "Wind" and "Distance" (Fig.9b); c) input variables "Wind" and "Angle" (Fig.9c). The constructed diagrams allow you to visualize the existing algorithm relationships between the output and input variables for a better understanding of the nature of the control process.

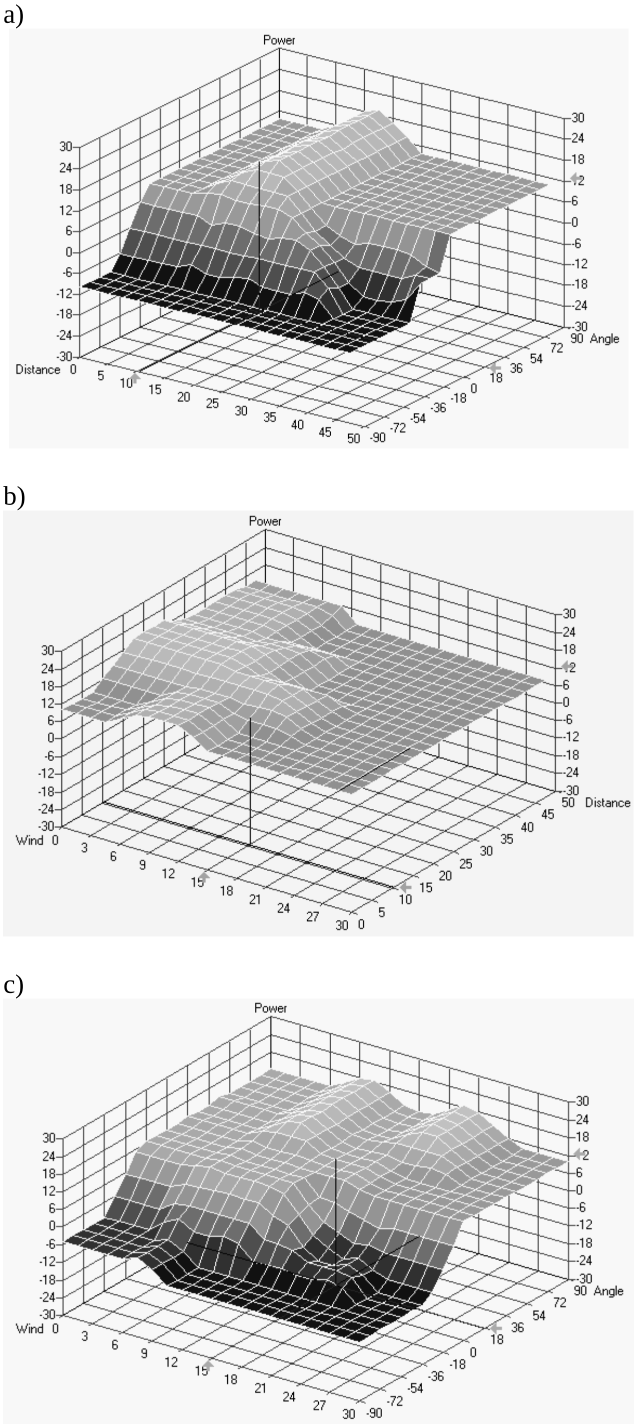


Fig.9. Diagrams 3D plots

## III. Conclusion

When developing the algorithm of the container crane control process using fuzzy modeling methods, two input linguistic variables are usually used, namely, the angle of the cable deviation from the vertical and the distance from the initial position of the load to its final position. Meanwhile, an important characteristic is the wind speed, since at high wind speeds it is necessary to carry out the movement of the cargo very carefully. At the same time, it is necessary to reduce the power of the drive motor of the truck of a container crane in order to avoid significant dynamic loads and to prevent fluctuations in cargo with a large amplitude. In this paper, such an algorithm is developed. Analysis of the algorithm showed a significant change in the required power of the drive engine, depending on the values of wind speed. The proposed algorithm will allow to carry out the process of moving cargo more efficiently with the least risk of crane failure and with the prevention of the cargo from any damage.

The proposed algorithm has a rather universal character and can be applied to the development of control algorithms for various processes, for the implementation of which it is necessary to take into account the influence of wind, for example, in wind generators, aircraft, floating vehicles and others.

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