Automated Systems & Technologies
14-15 June 2017 • St. Petersburg, Russia

A CONTROL SYSTEM OF SURGE REGULATION WITH NEURAL NETWORKS

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Abstract

In this paper, we are going to create a control system of surge regulation using neural networks for centrifugal compressors. We will describe a surge phenomenon in centrifugal compressors; explain how it happens and which approaches we have to avoid it; make a control system based on neural networks to predict a moment of compressor surging.
Keywords: compressor surge, control system, neural networks.

INTRODUCTION

Over the last fifty years the volume of production and the demands for product quality have increased, resulting in the development of industrial technologies. In this case, the demand for unstoppable working process, which has a big efficiency coefficient, becomes of major significance. Engineers develop new technologies of controlling processes or improve the old ones, basing on the industry demands. It is necessary for increasing economy and safety parts. In this paper an attempt has been done to improve technical and economical indicators of the centrifugal compressor basing on neural networks technologies[1].

The aim of the investigation is to develop and create a new system of the centrifugal compressor basing on neural networks. It can provide us with a better efficiency coefficient of using the compressor.

COMPRESSOR

A compressor is an energy machine or device to increase the pressure (compression) and movement of gaseous substances.

A compressor plant is a combination of a compressor, a drive and various additional equipment. This plant can be considered as a block where a gas under certain pressure is input, and at the output this pressure is increased by a certain number of times.

In this paper, we deal with centrifugal compressors because they have a compressor surge problem. Figure 1 shows the principle of action.

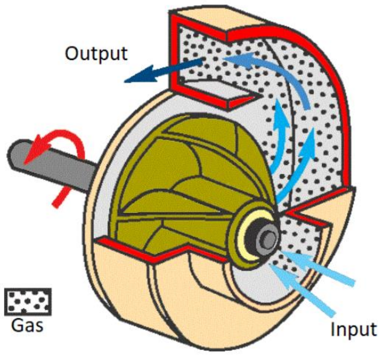

Figure 1 Principle of action

The rotational force is transmitted to the compressor shaft, which makes it spin around its axis. On the shaft there is a working wheel. The working wheel has vanes which have constant angle of slope. It allows us to improve the aerodynamic properties.

Getting onto the input side, the gas comes onto the vanes, which transmit energy to the gas molecules, making them move faster, and, consequently, the pressure is increasing.

It is worth noting that to increase the pressure to the required value, one stage is not always enough. In this case, the gas should go through several stages. Typically, one, two and four-stage compressors are most often used.

COMPRESSOR SURGE

As a rule, compressors are one of the many components of complex large systems, whose goals are very different. At the compressor design stage it is difficult to predict all areas where it can be used and predict all possible alarm situations that may arise due to external influences. One of the most dangerous and unpleasant phenomena is the surging of the compressor. The surge is periodic oscillations of the low frequency of the gas in the compressor. The surge arises from a sharp increase in the pressure difference between the suction and the compressor supercharger. It gives a reversal of the gas flow direction towards the suction side and a sharp increase in the outlet resistance of the machine. This phenomenon is accompanied by physical thrusts of the compressor.

The beginning of surging, as a rule, is accompanied by a reverse emission of gas into the suction part of the compressor, which provokes a sharp clap and a physical push. When the compressor is surging, its characteristics are changing (and can even be destroyed). The mathematical model of the compressor seems to get out of date, and we need to create a new one, which can be closer to real situations. In addition, the period of unattended operation of the machine is shortened. Apparently, the reasons are extremely negative, therefore, engineers of the industries where centrifugal compressors are used, together with developers, are trying to build a control system that would avoid compressor surges at high machine efficiency[2-5].

The point where the surging starts will depend on many components. Using Figure 2, we can see curve lines of the compressor. They are different, because they depend on a specific compressor.

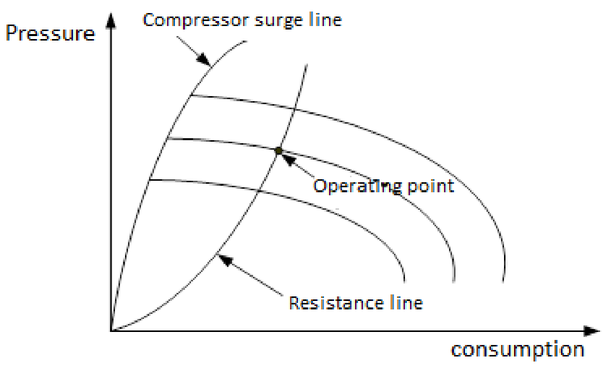

Figure 2. Operating point and compressor surge line.

This characteristic shows that the higher the pressure, the greater the increase in volume flow. At any given time, the operation of the compressor can be displayed by any one characteristic curve, and the compressor load is shown by any single resistance curve of the network. When the output pressure and the consumption (i.e., the operating point) satisfy both curves, it is a stable position.

The consumption at this point is such that the amount of energy supplied is equal to the amount of energy necessary to overcome the resistance of the network.

With increasing resistance, the operating point shifts up and to the left (because a higher pressure is required to maintain a constant flow rate). In the end, there comes a time when the compressor cannot increase the pressure to overcome the resistance of the gas; at this time we are at the point of maximum pressure. All such points define a curve, called the surge line. If the operating point is established to the left of the surge line, surging occurs; the flow rate and input pressure begin to pulsate and continue until the resistance of the network drops to a level that will be sufficient to restore a stable operating point. Thus, the task of control systems is to keep the point to the right of the surge line. All points like those show us the line which is called a surge line. When you are beyond this line, you have a compressor surge.

At present, regulation in classical control systems is based on the calculated data. When you receive information about the process characteristics, you can roughly calculate the operating point and the surge line for the compressor. If you are closer to the surge line or beyond the surge line, you can regulate it by decreasing the output pressure. It can be done with the aid of the bypass line or the ejection into the environment[6-9].

DEVELOPING OF THE SYSTEM

The algorithm

The algorithm was developed according to requirements. We can see the structure of the algorithm in the picture.

When we enter the program, the beginning is initialization of the variables. After that we obtain a table with compressor characteristics, which was obtained at the manufacture where the compressor was made. It contains the information about the characteristics of the compressor and when we can expect the surge. We need it to teach the neural networks. The teaching process will proceed via matlab, because LabView does not have enough opportunities for creating the neural net. Then we enter the loop which will be regular. We obtain all characteristics about the compressor from sensors and send it to the table of writing and to the graphs to show to the operator the condition of the compressor. Then we analyze the situation; first, we should understand what the operator wants.

One the figure 3: P1,P2 – input and output pressures, T1,T2 – input and output temperatures, C – speed of vanes, S – compressor surge value, Target – goal of vanes speed, Button – the button of NN relearning.

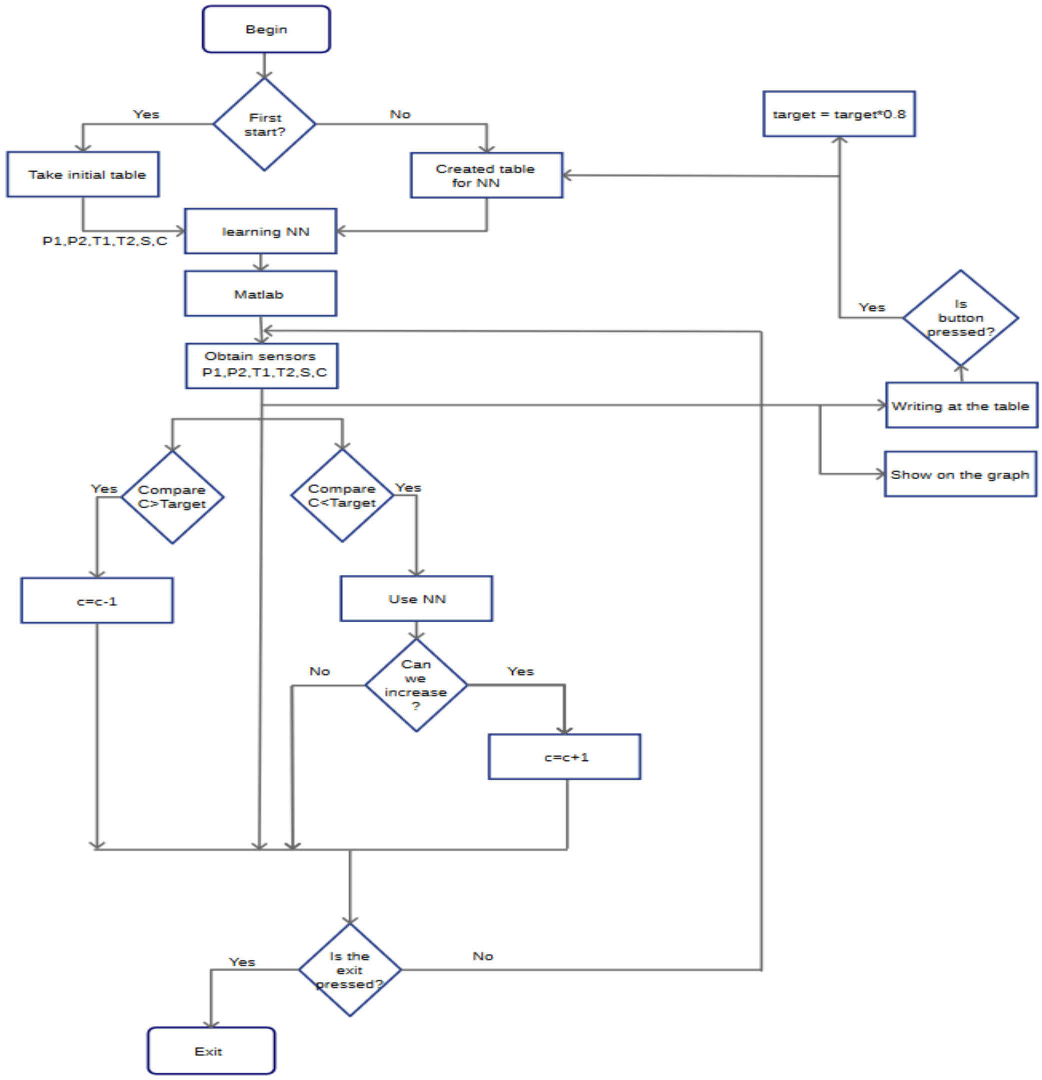

Figure 3. The algorithm.

If he wants to increase the speed of the vanes, we should define if we can do it or not. To do it, we send all the information from the sensors to the neural network. The neural network gets the following parameters at the input: temperature and pressure on the input and output side, and the speed of the vanes which we want to have. At the output the neural network tells us if we have the surge or not. Basing on the information, we can make a decision. If we increase the speed, we will have a surge; we forbid it and the speed will not change. If we can let us increase the speed and we will not have a surge, we do that.

If we want to decrease the speed, we do it without checking, because nothing can happen.

We always obtain the information from the sensors and write it in the table; it means we control the changes of the compressor and the environment. Parameters of the compressor's behavior change all the time. The main reasons are ageing, change in the gas parameters, change in the environment, etc. When we understand that we can work more efficiently, or that we often have surges, we can retrain the network. In this case, to avoid unpredictable situations, we should decrease the speed of the vanes by 20% and stick to it while the neural network is being retrained [10-12].

Modeling

Now we have had the algorithm, we can make the system. In the paper to create values from the sensors, we will use some dependents, which can relative the input and the output of the compressor. We use simple dependents for modeling which we can change if we have some real characteristics or values from the sensors.

If we split up the program on blocks we will have:

The first calculating node formulates the main input-output dependencies. It simulates values of the sensors. Here we can input characteristics of the compressor, but if we work with a real compressor, the node is not necessary.

The second calculating mode is a compressor line surge dependency. Here we can regulate the surge line; we can see how the behavior of the compressor will change if the compressor surge line is changed. Also, if we deal with a real compressor, it is not necessary.

The third block is regulation. It tracks the target date and changes the speed of the vanes according to the operator's requirements. We can say it is the block, which simulates the compressor behavior

The fourth block – is the block tracking the compressor surge. If everything goes well, the value will be zero, and if we come into the compressor surge area, the value is one. All values are written into the table. Then the information from the table is used for neural network learning.

The last block is the block of neural nets learning is waiting for pressing a button; if the button is pressed, the target value decrease by 20% and the learning process starts. Before that the data from the table are normalized and combined for NN learning.

Below you can see the program interface and results of modeling. The program interface includes all the necessary instruments to control the system.

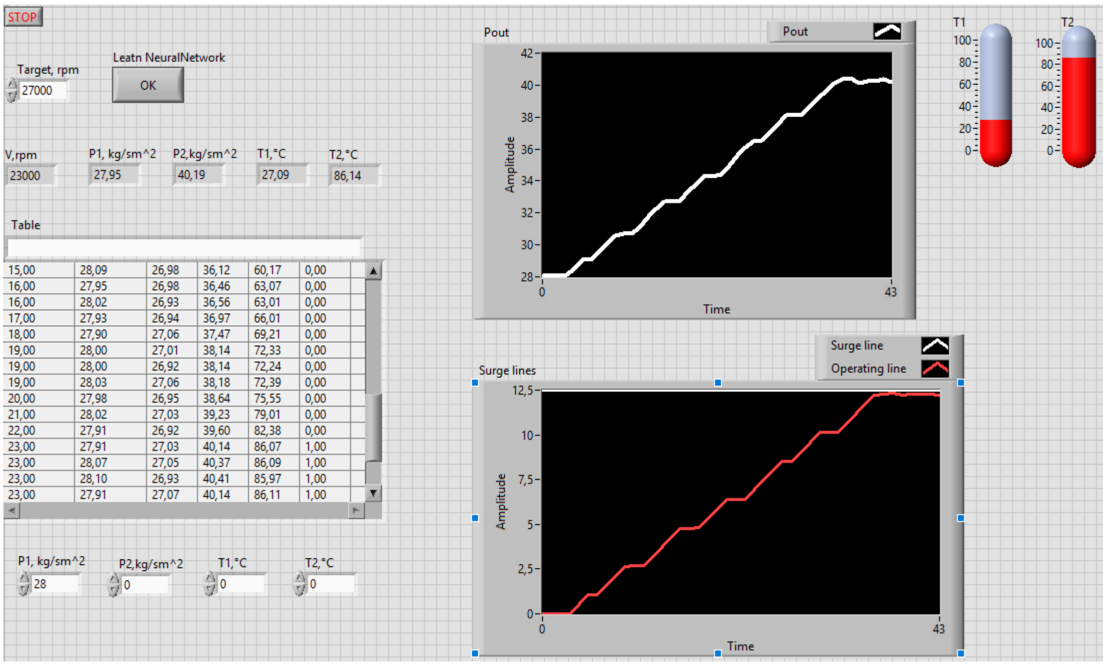

Figure 4. Human – machine interface. Work of the program.

You can choose the desired target of the speed of the vanes. If it is possible, after asking NN the speed will be increased.

You can also see here the system monitor. Here are the graphs of the output pressure. There are the thermometers of the input and output. The last graph is that of modelling. Here you can see the threshold, when we have the compressor surge and the operating conditional compressor line. If the operating line is higher than the second one, it means we have the compressor surge. The main purpose is to stick to the line as close as possible, but we can not cross it.

The buttons are instruments for changing any parameters. They work instead of environment or unpredictable situations. You can see the compressor's response to the changes, which have been made. Now let's simulate the program. The real data were taken from a real compressor. The gas is 97% hydrogen. You can see the work of the system. The table always replenishes itself. We can regulate the target of the compressor and see how the characteristics are changing. Our goal is 27000 rpm. But we have got close to the compressor surge when we have 23000. Then system does not let us increase the speed of the vanes. The last graph shows how close we are to the surge line (surge line = 12.5).

CONCLUSION

In this paper the compressor control system has been developed. It includes the theoretical part explaining why and when the centrifugal compressor has a surge, etc. Definitely, the system needs a lot of changes to improve characteristics, but totally, the system works. As for the changes, it is necessary to change the neural network's part, because in practice it is difficult to use LabView and Matlab at the same time. They do not have enough opportunities to solve the task. Besides, difficult dependencies have not been tested in the system. It means, when the system deals with a real process, it is necessary to correct the control system.

The system has some disadvantages. If we want to get the best behaviour of the compressor, we should add the bypass line of regulation.

REFERENTS

[1] Potekhin V.V., Chiem Xuan, Bykova V.I., Sulerova A.S. Process automation engineering within the concept of «Industry 4.0», Proceedings of the symposium automated systems and technologies, pp. 189-198, (2015)

[2] Mihaelov D.Y. Calculating pre-surge position gas facilities. Yang scientist. 18-22p., 2009

[3] Ylva Nilsson Modelling for Fuel Optimal Control of a Variable Compression Engine, 2007

[4] Magnus Pettersson Driveline Modeling and Control, 1997

[5] Potekhin V.V., Goloshchapov E.S., Zobnin S.S., Ipatov O.S., Fedorov A.V., Shkodyrev V.P. Aspects of smart manufacturing via agent-based approach, Proceedings of 25th DAAAM International Symposium on Intelligent Manufacturing and Automation, (2014)

[6] Aurel Stodola (1945). Steam and Gas Turbines. New York: P. Smith.

[7] Potekhin V.V., Leming M.J., Amrajei A.N., Kovalevsky V.E. Intelligent Information Measuring System for Monitoring and Optimisation of Energy Consumption, Proceedings of the Distributed Intelligent Systems and Technologies Workshop, St. Petersburg, Russia, 1-4 July 2013, pp. 81-88, (2013)

[8] Potekhin V.V., Niemann B., Overmeyer L., Shkodyrev V.P., Shchekutin N.O. Intelligent Control Systems and Networks: Theory and Applications, Results of Joint Research Activity of Scientists from Saint-Petesburg State Polytechnical University and Leibniz University of Hannover, pp. 82-94, (2014)

[9] Kerrebrock, Jack L. "Aircraft Engines and Gas Turbines", 2nd edition. Cambridge, Massachusetts: The MIT Press, 1992.

[10] W. R. Hawthorne (1964). Aerodynamics Of Turbines and Compressors. Princeton New Jersey: Princeton University Press.

[11] Potekhin V.V., Vasilieva A.V., Tyzhnenko D.A. Modelling of intelligent informational system for monitoring and optimisation of power consumption, 2nd international conference on advanced in computing, engineering and learning technologies, pp. 11-17, (2014)

[12] Potekhin V.V., Valov P.M., Kovalevsky V.E., Shkodyrev V.P. Distributed Situation-Specific Control in Prevention of Emergency Situations in Continuous Manufacturing, Proceedings of the Distributed Intelligent Systems and Technologies Workshop, St. Petersburg, Russia, 28-30 September 2011, pp. 63-72, (2011)