Condition Based Maintenance Monitoring of Gear Box Using Fuzzy Logic Systems

Mushiri Tawanda, and Mbohwa Charles

Abstract—The purpose of this research was to come up with an intelligent monitoring tool to reduce the number of breakdowns of a beverage company bottle washer. The Fuzzy Logic system was derived among other artificial intelligent systems to be best appropriate to solve the breakdown challenges of the bottle washer. A gearbox is always jamming and it's not easy to troubleshoot the breakdown cause and fuzzy logic is a tool that was used for monitoring. The researchers carried out a company audit, interviews and administered questionnaires in order to gather relevant data. The results were used in intelligent condition-based-maintenance modelling to solve the problem using fuzzy logic system and it was found that oil level should be always above 40% otherwise the gearbox will be made to stop. Torque is supposed to have a range of values accepted from 0-8 000Nm beyond that we consider the stoppage of the gearbox.

Keywords— Condition Based Maintenance (CBM), Fuzzy Logic, Gearbox, Krones Machinery.

I. Introduction

MAINTENANCE of equipment is very vital activity among other process segments. Downtime is one of the most costly conditions a manufacturer can reluctantly experience. A proactive technical support program which can generate significant cost savings can be developed. Continuous-monitoring services can also generate cost savings by protecting existing investments. The case study that the researchers used refers to a company that installed the Krones machinery. A cleaning machine is used to ensure that any bottles being filled are free from contaminants. Bottles are washed both inside and outside and then dried by the bottle washer as shown in figure 1.

The temperature and pressure in this machine can be accomplished in monitoring by using an artificial intelligent system. Temperature variations that come from the boiler might cause some problems to the bottle washer, so control and monitoring devices like the poka-yoke system can be used to control the hotness and coldness of water before entering the machine. This is a proactive type of maintenance to prevent breakdowns and unnecessary shutdowns doing crisis maintenance,.

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Fig 1: Bottle washer (http.www.krones.com)

A. Objectives

Determine the required levels of oil level for the gearbox not to jam using fuzzy logic principle as well as control torque. Torque should be not as high as to strain the gearbox, so the fuzzy logic is going to monitor required values for the given range 0 to 12 000Nm, a suitable range is now to be found.

B. Methodology

The research started by the researchers visiting an anonymous company to find out more the bottle washer. A questionnaire was prepared and it took into account a lot of factors. It was prepared for the technical staff only which was engineers and artisans. The information was obtained from the engineers (two of them), artisans (three) and operators (three) and also from the records of maintenance history since the plant was installed in the year 2011.

It was found out that preventive maintenance is carried out to the whole plant as well as condition based maintenance but the problems of breakdowns are persisting. Sometimes budgets for maintenance are not preferred to and as a result not done sometimes. A software called Coswin 7i in Computerised Maintenance and Management Systems (CMMS) is used. Some staff which work in the technical need more workshops and trainings to enhance their skills. It was observed that no standard operating procedures (SOPs) were there to machines which cause problems too. The major problem that remained a bottleneck was the gearbox which jams most of the times and being caused by oil level when it is low and also when torque overshoots. This is where the researchers chipped to come up with intelligent fuzzy logic CBM approach to eliminate the problem. A number of tools were used and softwares; MATLAB with fuzzy logic was the main software to determine required values for the oil level in the gear box and

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the torque. Edraw max was used to draw the Ishikawa diagram. Programming was done to control the parameters that were a problem. The researchers were also involved in the day to day running of the plant for six months trying to identify problems why they persist.

C. Justification

Intelligent systems make it possible for engineers to make decisions faster with what they will be seeing. Much time, cost and energy for the user is saved especially to those who are in hurry as they don't have to call engineers / specialists who manufactured the bottle washer for maintenance. Fuzzy logic gets the peoples even more closer to the world of computerisation and technology. Problems can be solved faster and easier. Technical team are sometimes not able to troubleshoot the problems of torque and oil level to the gear box.

D. Limitations Of The Study

Only fuzzy logic is to be used in this research hybridised with CBM to monitor the gearbox of a bottle washer as in figure 1.

II. Condition Based Maintenance As A Subset Of Reliability Centred Maintenance

Since CBM is a branch of RCM, the researchers found it necessary to explain what it is briefly. In this paper intelligent CBM is to be carried out. The major reductions in routine operations and scheduling leads directly to large reductions in operations cost (Kiinigsmann, 1996). This is because equipment can revert to systemic failure even after maintenance has been carried out if due regard to maintenance instructions is not adhered to. Reliability Centred Maintenance (RCM) is much more than just another way to do maintenance. In a nutshell, it is a way of looking at system performance in terms of the impact of a failure and then mitigating those results by design, detection, or effective maintenance (Wheeler, 2007). RCM develops a comprehensive data base of maintenance requirements, skills required and stocks that should be held (Zhongwei, 2010). In addition, RCM also has an important role in overall system safety management (Rausand, 2008). Within RCM, the optimal reliability threshold is determined by minimizing the cumulative maintenance cost per unit time in the residual life of the system (Xiaojun. 2007).

Multi-skilling is one such approach which bridges the gap between corporate and individual interest (Huselid, 1995). Each group member should also have been trained in RCM and thoroughly equipped with team working skills (Hackman, 2002). Maintenance management has found new vigor and purpose to increase equipment capacity and capability due to increasing focus on lean manufacturing in today's competitive environment. Tremendous efforts have been made to develop different types of maintenance strategies for enhancing the performance of equipment (Sawhney, 2009) but equipment continues to fail. From a review of present maintenance policies in electric utilities, it is concluded that maintenance at fixed intervals is the most frequently used approach, often augmented by additional corrections (Endrenyi. 2001). General preventive maintenance, which does not return equipment to the as new condition, is appropriate for equipment subject to constant failure rate (Levitt, 1988). It has dawned now to the researchers to work with intelligent CBM which highlight exactly where the problem is what needs to be done to maintain the plant running at full capacity as stated. Preventive maintenance is good but it tends to be expensive as it is like a machine gun firing approach rather than being specific. Intelligent CBM is seriously a solution in this current time of high technology and kaizen philosophy is the word of the day.

Failures in traditional maintenance have the potential for being disastrous for the equipment as opposed to CBM as there is ample time to analyze the potential failure and execute a recovery plan (Kiinigsmann, 1996). Condition based maintenance is a management philosophy that posits repair or replacement decisions on the current or future condition of assets (Raheja, Llinas, Nagi, and Romanowski, 2006); it recognizes that change in condition and/or performance of an asset is the main reason for executing maintenance (Horner, El-Haram, and Munns, 1997). CBM has a newer kind of approach as we can see but going forward with the intelligent CBM incorporated by programmable logic controller breakdowns will be eliminated greatly.

III. Fuzzy Logic Systems

Fuzzy logic is widely used in machine control. The term itself inspires a certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic", but the "fuzzy" part does not refer to a lack of vigor in the method, rather to the fact that the logic involved can deal with fuzzy concepts - concepts that cannot be expressed as "true" or "false" but rather as "partially true". Although genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases (in fact, certain neural networks can be shown to be mathematically equivalent to certain fuzzy logic systems), fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans (Yao, 1994). A logic based on the two truth values TRUE and FALSE is sometimes inadequate when describing human reasoning. Fuzzy logic uses the whole interval between 0 (FALSE) and 1(TRUE) to describe human reasoning. As a result, fuzzy logic is being applied in rule based automatic controllers (Jantzen 1998). A fuzzy logic controller consists of 4 main components, a Fuzzifier, inference engine, knowledge base and a defuzzifier. This is shown in Fig 2 (S. B. Mohd Noor, 2004)

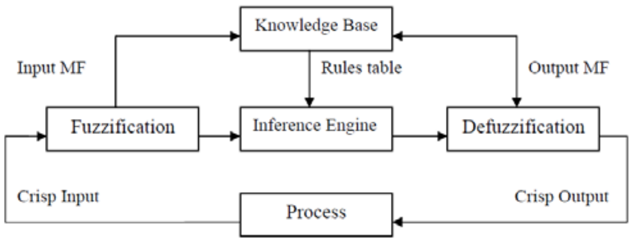

Fig. 2 Fuzzy logic Control

A. *Fuzzy Rules*

Fuzzy rules are used in fuzzy control in order to define the map from the fuzzified input signals (error signals, measured signals or command signals) of the fuzzy controller to its fuzzy output signals or control signals. We have fuzzy Single input, single output (SISO) rules, fuzzy AND rules and fuzzy OR rules (Geering 1998). A connection between cause and effect, or a condition and a consequence is made by reasoning. Reasoning can be expressed by a logical inference or by the evaluation of inputs in order to draw a conclusion. We usually follow rules of inference which have the form: IF cause1 = A and cause2 = B THEN effect = C. Where A, B and C are linguistic variables. For example, IF “room temperature” is Medium THEN “set fan speed to Fast” Medium is a function defining degrees of room temperature while Fast is a function defining degrees of speed. The intelligence lies in associating those two terms by means of an inference expressed in heuristic IF…THEN terms (Simoes 2001).

IV. Bottle Washer

A cleaning machine is used to ensure that any bottles being filled are free from contaminants. Bottles are washed both inside and outside and then dried. The plan for a typical bottle washing machine is shown in Figure 3. Hazards associated with cleaning machines include mechanical crushing and stabbing between cleaning nozzle and container (BS EN 415-2:2000). The temperature and chemical composition of the cleaning fluid is also a hazard as it is typically hot and toxic.

A. *Inteligent Monitoring Method*

The parameters in this machine can be accomplished in monitoring by using the fuzzy logic. Temperature variations that comes from the boiler might cause some problems to the bottle washer, so poka yoke devices can be used to control how hot and cold the water is before entering the machine.

B. *What To Monitor At The Washer*

It is also of particular interest to monitor the water that enters the bottle washer to avoid corrosion in the elements of the washer. Figure 3 shows temperature, time and other chemicals in the washer need to be monitored and controlled to cater for the prevention of rust and wear due to foreign particles.

TABLE I
TECHNICAL DATA FOR THE BOTTLE WASHER FROM BEVERAGE

Parameter	**Capacity**	**Parameter**	**Capacity**
Capacity	50 400bph	Pre soak	2.58m^3
Min adjustment range	21 000bph	Pre spraying 1 and 2 sides	0.3m^3
Max adjustment range	61 000bph	Caustic tank 1	57.10m^3
Processing time	24.14mins	Caustic tank 2	57.10m^3
Cycle time	2.93mins	Caustic tank 3	N/A
Bottles per carrier	41	Post caustic	7.77m^3
No of carriers	615	Warm water 1	2.26m^3
No of bottles per machine	20 295PCE	Warm water 2	2.56m^3
Empty weight	135t	Cold water	2.17m^3
Operating weight	279t	Total water consumption	11.38m^3/h
Machine length	17 053m	Machine width	9 515m
Machine height	5.2m	High pressure pre jetting	0.6m3

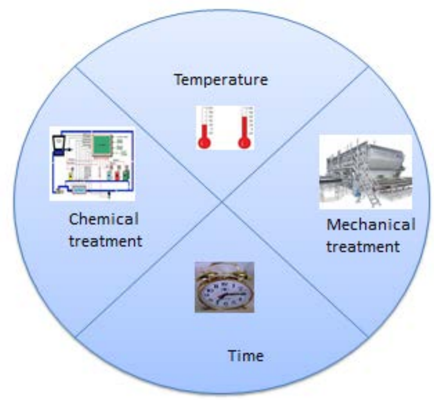

Fig 3 Components to be monitored at the washer (drawn in power point)

The broad range of bottle washers provides successful clean¬ing for all applications: In sophisti-cated concepts, the glass and plastic bottles, which are in use worldwide since many years, will be extensively cleaned and gently treated. Clean and highly polished beverage and food packs meet the marketing require¬ments for an optimal presence of your product in the market.

The machines of the single-end series KE are compact and very efficient, and they can be tailored to fit any individual application. The extensive variety includes different guard heights and offers a broad range for combining different modules for the heating and caustic zones. The chain loop guide inside the machines allows for a long retention period of the bottles in the baths. Furthermore, the arrangement of the label removal is optimally adjusted to the line performance. Another plus point of the machine features is the gentle container conveyance especially in the container in feed and discharge area.

V. Problems

The gearbox jamming problems make the bottle washer inefficient. One of them might be a cause that stops the washer and increase downtimes for the equipment.

A. Technical Data For Bottle Washer

It was found that torque was contributing to some jamming of the gearbox. Figure 4 shows how torque is transmitted in the bottle washer from the time the bottles are inserted up until they come out. The question now is to find a solution of the range of torques that is necessary to avoid jamming.

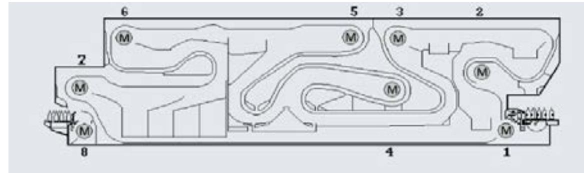

Fig. 4 Electric motors around the washer, the chain and their rated torque in Table II (http.www.krones.com)

TABLE II
TORQUE RANGES FOR THE DIFFERENT AREAS OF OPERATION OF TORQUE AROUND THE WASHER

UNITSOF TORQUE (Nm)	Nm	Nm	Nm	Nm	Nm	Nm	Nm
	2	3	4	5	6	7	8
	202	204	204	204	204	204	204
	74	76	76	78	76	76	76
ACTUAL TENSION (N)	0	0	0	0	0	0	0
TENSION SET POINT (N)	20	28	34	52	38	42	
ACTUAL TORQUE (Nm)	6020	1390	730	1200	290	480	0
RATED TORQUE (Nm)	12000	8000	8000	8000	8000	8000	4000

Table II here now shows the numerical values that were obtained in doing the research. The numbers 2 up to 8 at the top means different areas of movement of bottles around the washer from the time of insertion up until it is removed. The torque varies rapidly.

VI. FINDINGS AND DISCUSSIONS

From figure 3 the researchers came up with problems from the bottle washer and put the cause and effect diagram which were formulated by the Japanese founder of seven causes which are: Methods, Machinery, Management, Materials, Manpower; Environment and Measurement. Ishikawa diagrams (also called fishbone diagrams, or herringbone diagrams , cause-and-effect diagrams, or Fishikawa) are causal diagrams that show the causes of a specific event -- created by Kaoru Ishikawa (1968). Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Gearbox jamming was also fitted to be identified problems using the Ishikawa diagram. This is rather literature review which can be used in that section or as part of methodology. Therefore the researchers came up with possible causes of the gearbox jamming and mostly from the workers at the company it revealed the ones in figure 5 below.

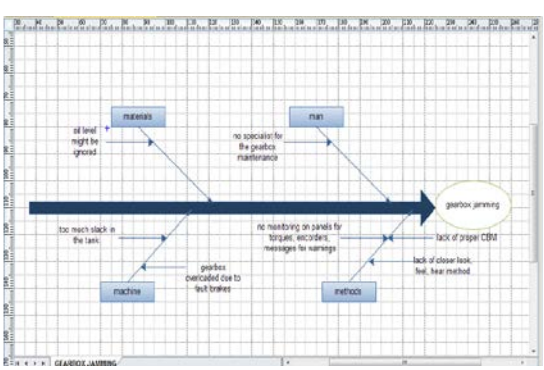

Fig. 5 Ishikawa diagram developed for gearbox jamming

For the four causes from man, methods, machine and materials it was found out that man's problems can be solved by trainings, workshops and other necessary ways to make sure that they do not cause jamming either inevitable or not. Machine problems can also be controlled by supervision by the superior of the artisans at the company. The remaining problems caused by materials and methods those are the ones the researchers put on intelligent control since they are recurring. At the company there is a supervisory control and data acquisition system (SCADA) which shows the messages from the plant that torque is high or whatever the value and put a red indication to show attention by staff. It is not easy to clear off these messages because you cannot identify where exactly that error to the whole bottle washer is. Too much torque causes jamming and hence needs fuzzy logic control. It also came into the mind of researchers to control as well oil level and put fuzzy logic to perform the way modern vehicles are programmed to indicate their fuel gauge whether it is high, or whatever level giving an indication to the driver to know when to refill again. This is how fuzzy logic will come in. No human can control that except artificial intelligence to avoid unnecessary breakdowns.

A. Control Of Gearbox Jamming Using Oil Level And Torque [Fuzzy Logic Using Matlab Software]

The researcher managed to find out that the reasons that causes gearbox jamming are oil level and torque when the washer is loaded. Oil level was controlled and is to be programmed with certain levels. Low, medium and high are to be used which indicate about to finish and needs replenishment, is fine and is still there respectively. Values were suggested for the ranges as shown

Oil level: [0 – 100%] (this is the range of oil in the gear box at any time):

Low; 0 – 40%; (this defines when oil is about to be empty, this should put an indication to the artisans for refilling)

Medium; 40 – 80%; (the level is fine and the gear box to continue running)

High; 80 – 100%; (the level is very fine and the gear box to continue running)

The same is to be done to the torque control

Torque: [0 – 12000Nm] this is as shown in table 2 (whole range):

0 – 2000Nm Very low (very fine for starting the gearbox but is fine for running the bottle washer) ;

2000 – 8000Nm Normal (torque is fine);

8000 – 12000Nm Very high (needs close monitoring or otherwise stop the washer).

The gearbox has to be stopped when bad conditions exist in the washer as a proactive maintenance strategy to avoid jamming, hence intelligent fuzzy logic control.

Gearbox: [0 – 100%] (it has to run or not run, either of the 2, that is the meaning of 0 for stop and 100% for running that is the 0 or 1 for logic:

0 stop (machinery to stop being controlled by the inputs which are oil level and torque, when all is well it can run);

0 stop (since we need to program it to the triangular fuzzy logic software on MATLAB we should have this zero in the middle for the software to recognise its presence;

0 – 100% run (that is, all the conditions are met)

Figure 6 below shows the 2 inputs oil level and torque and the output is the gearbox.

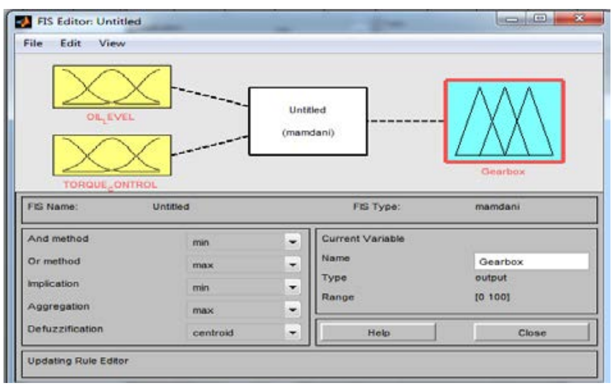

Fig. 6 FIS editor for the gearbox jamming

In MATLAB software for the fuzzy logic, there are some conditions and rules to be implemented for these inputs to be controlled not to affect the gearbox. The ranges as explained for both oil level and torque needs to be inserted. These were put into the software and a print screen of the data was taken by the researchers as shown in figure 6. This is called the fuzzy inference system (FIS)

For the values and ranges of the system that were suggested by the researchers they were added into the software and automatically they become members of the system and this stage is called the membership function editor. Oil level has to have its three ranges of low, medium and high as shown earlier on. This is shown in figure 7. The same applies to the torque.

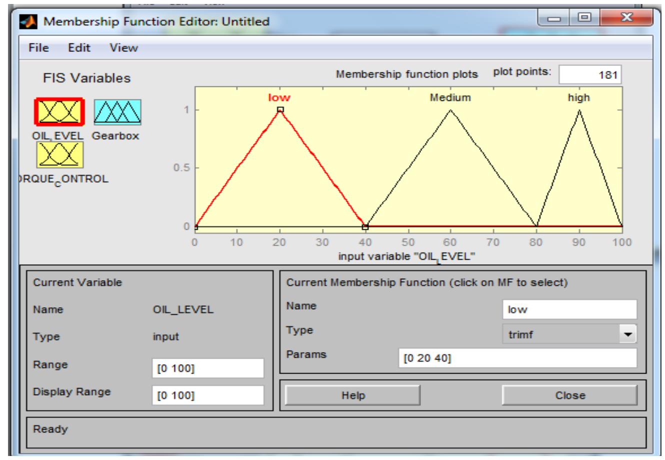

Fig. 7 Membership function editor for oil monitoring

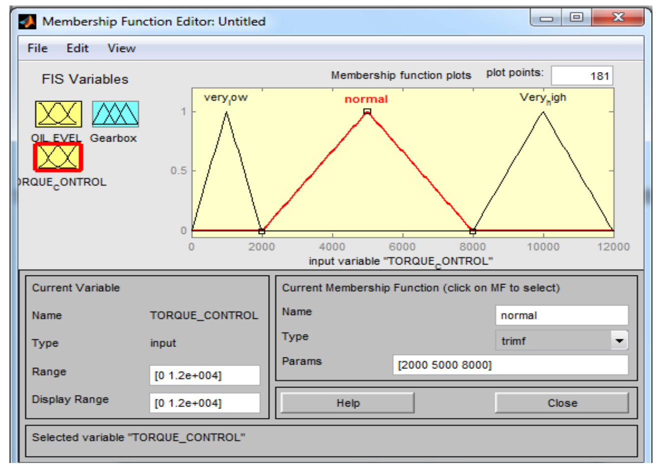

Fig. 8 Membership function editor for torque monitoring

Figure 8 shows torque control now and it is shown there clearly with the ranges of very low, normal and very high and also the numerical values added. The software now reads these as members in its programming and simulations.

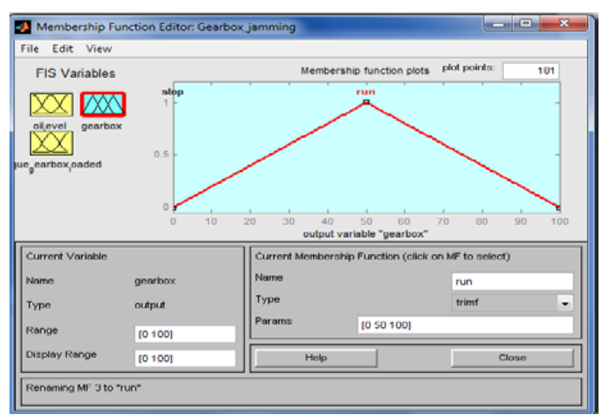

Fig. 9 Membership function editor of the output, gearbox

Membership functions also for the gearbox are inserted and plot the triangle in figure 9. The software now will store this in its memory since it is intelligent and will learn also to the system and reasons what can be done since it is fuzzy logic, a branch of artificial intelligence.

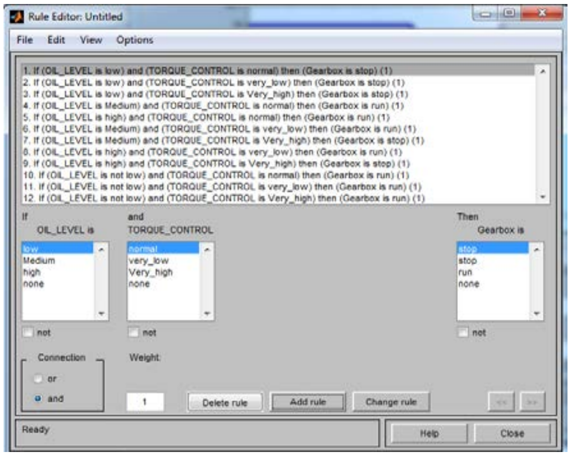

Fig. 10 Rule editor for gearbox jamming

After inserting the values of inputs and outputs into the software of MATLAB with fuzzy logic, rules are to be generated and it is seen that fuzzy here has the IF…..THEN……ELSE rules in its programme already so retrofitting our values there will make it reason and use that forever unless or otherwise programmed to change. So here 12 rules were generated as seen in figure 10 above. The ranges of low, medium and high for oil level are generated automatically by the intelligent fuzzy and then you click and select the rules as per your instructions. Likewise the torque was done the same way for normal, very low and very high. The none in each case in the software represents anything you may need to include again which you had forgotten from the beginning. So the add rule button is the one that is clicked to add a rule in the inference engine of the fuzzy logic. If you want to edit a rule or remove it you click delete rule and it's removed, you can as well change rules.

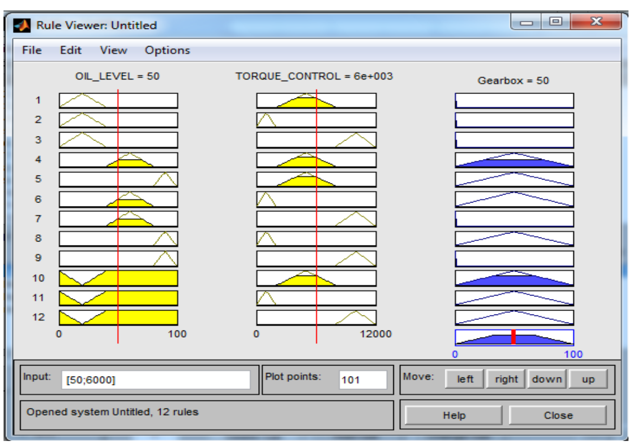

Fig. 11 Rule viewer for the gearbox monitoring

After the rules are created they are viewed by the intelligent software as shown in figure 11. Oil level, torque control and gearbox are shown clearly in figure and the values above are just ranges and not taken as conclusions for control. Conclusions are only taken in the defuzzification process as in figure 12 below.

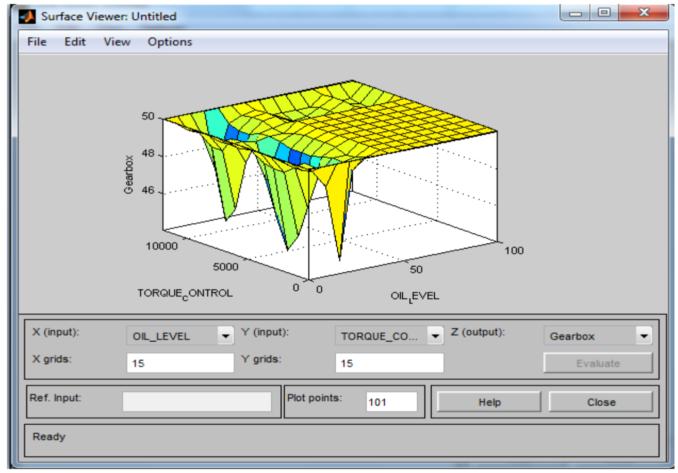

Fig. 12 Surface viewer for the gearbox monitoring

Finally on our software a 3Dimensional structure like this is obtained in figure 12 and this gives conclusion to the range of values of the inputs that are required. This can be put in 2dimensional and is simplified as shown in figure 13 below.

B. *Control Of Gearbox Torque And Oil Level.*

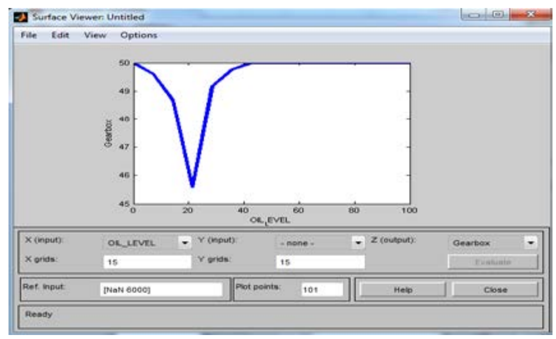

Fig. 13 Surface viewer of gearbox control using torque and oil level.

From figure 13 it shows that gearbox remains constant and runs at 50% capacity if the value of oil level is 40% for smooth running of the bottle washer. So this shows oil level should not by any means be below 40% otherwise stop the gearbox to run to avoid problems. The fuzzy logic will instruct the machine to stop without human intervention. So this is the elimination of the problem of less oil in the system. Objective has been accomplished.

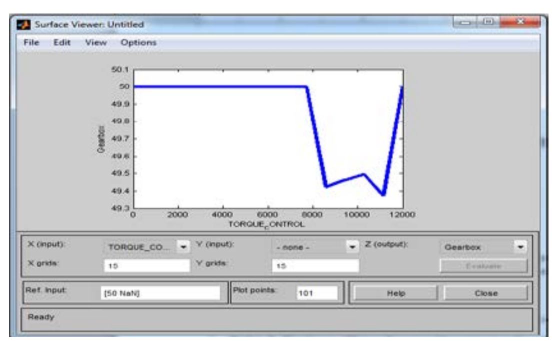

Fig. 14 Surface viewer of gearbox control using torque

Gearbox remains running at 50% capacity and the value of torque should not be more than 8 000Nm. By this figure 14 it highlights that torque should not exceed 8 000Nm otherwise stop the gearbox hence the whole bottle washer stopped. Fuzzy logic has put this data in its fuzzy inference engine and will continually control this set up, all conditions have to be met for the gearbox to run.

VII. Conclusion

The objectives of the research were met. Oil level should be always above 40% otherwise the gearbox will not run. Torque also is supposed to be having a range of values accepted from 0 to 8 000Nm beyond that we consider the stoppage of the gearbox. The bottle washer will be connected with this programmed fuzzy controller and maintains the rules in its system and act as per request. This is an intelligent fuzzy logic condition based maintenance control in the fact that CBM is supposed to be act as when necessary but sometimes with latest automated equipment being manufactured nowadays, it will be a complex thing altogether to work with CBM alone. A hybrid of CBM and fuzzy logic programmed controller as done by researchers will solve a lot of problems.

A. Future Work

Appropriate components need to be worked out their actual technical values like sensors, size of SCADA, programmable logic controllers and other materials of particular importance for the installation of this intelligent maintenance at this anonymous company

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