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AIR COMPRESSOR CONDITION MONITORING ANALYSIS

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ABSTRACT

A ship may be autonomous in personnel and material. This implies that the equipment onboard will work continuously without exterior intervention. The crew will be responsible for equipment operation and maintainability. Our investigation intends to contribute to a design of a monitoring system that can enhance the equipment reliability and allow the continuous knowledge of its state. In this study, we consider a specific equipment, an air compressor. In a ship an air compressor can be electro or motorized. The compressor can assume various mechanical shapes according to its applications specificities and environment. Although, the existence of redundancy, it may be considered a selected equipment in a warship condition monitoring system. This is a vital equipment for propulsion, power generating system and weapon operations. The considered air compressor has a preventive maintenance system management implemented. Various condition monitoring techniques may be applied to air compressor such has ultra-sound, oil analysis, thermography, and current analysis for electro-compressors, etc. For the air compressor under study, we propose an online condition monitoring considering the vibration measure, applying some statistic technics.

Keywords: Air Compressor, Condition Monitoring, Vibration, Statistical Methods.

INTRODUCTION

Air compressor good performance is important to industry plant and to ships, its condition monitoring (ex. Oil control and vibrations) is crucial for other equipment's and technical tasks. (Li et al, 2012) (jiang et al, 2011)

In this article, statistical techniques will be applied to vibration data collected from an air compressor.

The use of non-destructives Techniques such as vibration (Randall, 2011) and acoustic measures, and oil analysis may allow the determination of an equipment and system state (Benedetti, 2018).

In a study of air compressor maintenance and its condition, allied to vibration measure collecting data and then proceed to short run control charts statistic application techniques may allow an enhance of the equipment performance. (Qiu, 2020)

This is a very important study to ship equipment condition monitoring. In condition monitoring, the combined study applying statistic techniques to air compressor, such as control charts, it's a knowledge "win win". Various articles on this thematic can be found with simple research in the internet. In Fig. 1 is shown a sample of simplified search done in a histogram of articles thematic.

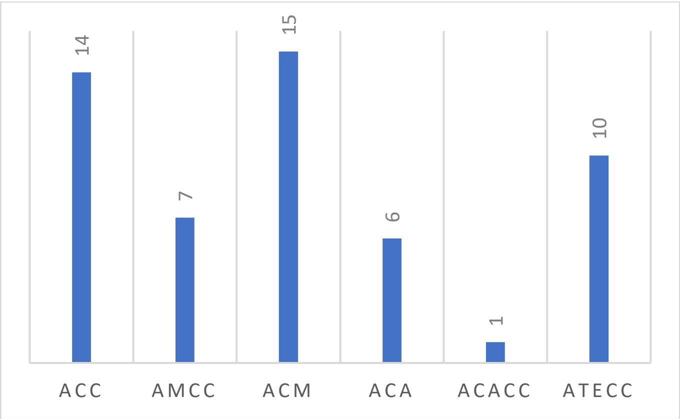

Fig. 1 - Thematic Research Histogram

The thematic mean is in table nr 1:

Table 1 - Thematic meanings

ACC	- Artigos Control Charts/Control Charts Articles
AMCC	- Artigos Modified Control Charts/Modified Control Charts articles
ACM	- Artigos Controlo de Condição/ Condition Monitoring Articles
ACA	- Artigos Compressores de Ar/Air compressor articles
ACACC	- Artigos Compressor Ar e Cartas Controlo/Air compressor and control charts articles
ATECC	- Artigos Técnicas Estatísticas em controlo de condição/Statistic tecniques in Condition Monitoring articles

STATISTICAL TECHNIQUES – SHORT RUN CONTROL CHARTS

Without enough data, it is not possible to estimate the parameters, mean and the standard deviation, of some processes, in this case equipment. In addition, in the present case, the reason is that the sample is too short to represent a functioning standard. In these cases, *Charles Quesenberry* methodology is applied.
Because it is not possible to control, the mean of continuous variable X we transform the variable in variable Q. the characteristic Q in the r instant is (Pereira & Requeijo, 2012):

$$Q_r\left(X_r\right)=\Phi^{-1}\left(G_{r-2}\left(\sqrt{\frac{r-1}{r}}\left(\frac{X_r-(\mu)_{r-1}}{S_{r-1}}\right)\right)\right),\ r=4{,}5,\ldots \qquad (1)$$

Note that in equation nr 1 we use the mean (not modified) and in equation nr 2 we use the $(T_L)_{r-1}$ that represent the defined limit.

$$Q_r(X_r) = \Phi^{-1}\left(G_{r-2}\left(\sqrt{\frac{r-1}{r}}\left(\frac{X_r - (T_L)_{r-1}}{S_{r-1}}\right)\right)\right), \ r = 4,5,\ldots \quad (2)$$

In this chart there is only one phase, and the graphics are design considering: the points $(r, Q_r(X_r))$, where $Q(X)$ is the control chart, and it will be called *QM* control charts. This chart allows the mean control since observation nr 4 (*r=4*). And the difference from the original Q charts and to the modified is that the value $\overline{X}_{r-1}$ is substituted by $(T_L)_{r-1}$, which represent the limited defined by the technical direction. (Lampreia *et al*, 2012) (Lampreia et al, 2013). Because of the data we are controlling, vibrations, we only will consider the maximum values, so for *Q* only values equal or higher than 0 is consider (Quesenberry, 1996).

The mean and variance in instant *r* é:

$$\overline{X}_r = \frac{1}{r}\sum_{j=1}^{r} X_j \quad (3)$$

$$S_r^2 = \frac{1}{r-1}\sum_{j=1}^{r}\left(X_j - \overline{X}_r\right)^2 \quad (4)$$

The mean and variance in the instant r $\left(\overline{X}_r \text{ e } S_r^2\right)$, can be calculated in function of X_r and in function of the previous values $(r-1)$ (Snoussi, 2006).

The variables in equations nr 3 and nr 4 are (Pereira & Requeijo, 2012):

X_r	-	Observation in instant r.
$(T_L)_{r-1}$	-	Vibration Limit $(T_L)_r = (T_L)_N - 3\sigma_{r-1}$ for observation nr $(r-1)$, where $(T_L)_N$ is the limit.
S_{r-1}	-	Standard deviation of $(r-1)$.
$\Phi^{-1}(\bullet)$	-	Reverse normal distribution function.
$G_\nu(\bullet)$	-	T-student distribution in function of ν freedom degree.
μ	-	Mean.

The variable $Q(X)$ have a distribution $N(0,1)$, considering only the maximum values the limit for the charts are:

$$LSC_Q = 3 \quad (5)$$

$$LC_Q = 0 \quad (6)$$

The analysis of Q_X modified control chart is different from the *Q(X)* traditional, so the rules of intervention are going to be defined.

MODIFIED SHORT RUN CONTROL CHARTS – METHODOLOGY

The analysis of the Modified QX its different from Q(X) control charts, because of the modification on the chart, and because it is considered the maximum value and not the mean of this value.

We propose applying the Modified Control Charts in condition based maintenance statistical methodology. The proposal is:

- Define the study parameters;
- Continuously collect vibration data from the define points of measure;
- The vibration functioning parameters, mean and standard deviation, are calculated each instant;
- Apply the modified short run control chart and proceed to the next actions:
  - When 8 consecutive observations are above the AL proceed to a more frequently observation, eventually apply some other complementary non-destructives tests;
  - When more than 3 observations are above the UCL, the anomaly should be perfectly identified and a maintenance intervention should take place.

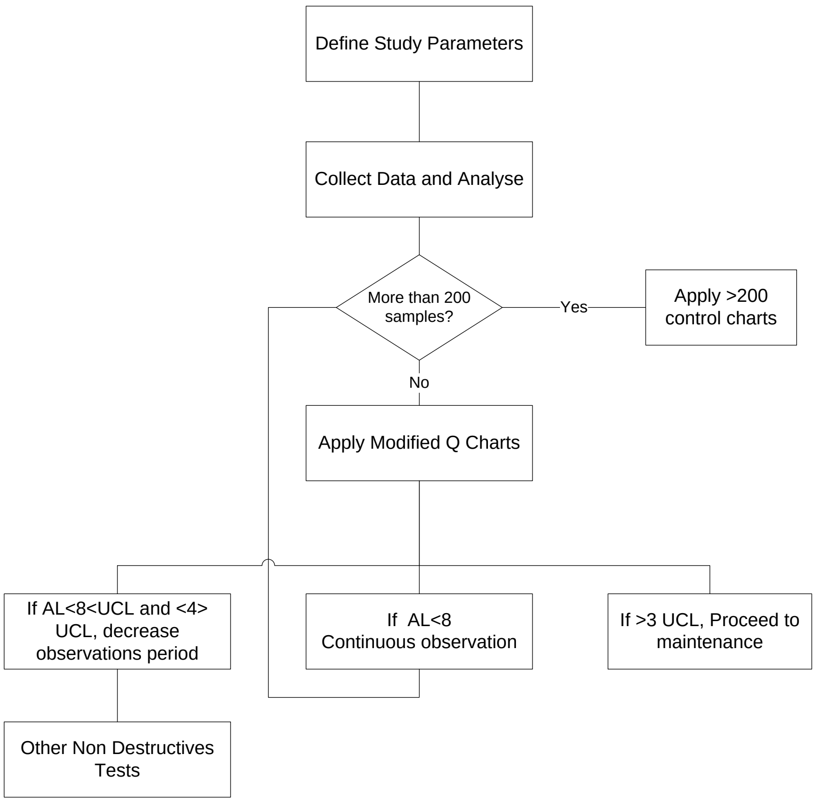

Fig. 2 – QM control chart methodology

CASE STUDY - AIR COMPRESSOR CONDITION MONITORING

Air Compressor – Equipment under study

The equipment under study are air compressor, Fig. 3, six from three ships (ship nr 1, ship nr2 and ship 3). Its characteristics are:

- Reciprocating;
- 2 cylinders, "V"
- 3 stages
- 62 m^3/h
- 1ª and 2ª stages allowed with a double effect cylinder;
- Air cooled;
- Electric engine with 16,5 KW-440 V – 60HZ
- 1170 rpm.

Fig. 3 – Air Compressor

In the ships there are two low pressure air compressor, it is physically one in the diesel engine room and the other in the gas turbine room. This system allows the diesel engines start, and also is an auxiliary system in the control of other equipment, and workshop multitasks. We obtain data from two point of the electric engine of the compressor (point A and B) and data from one point of the compressor (point C), it is discriminated in the table nr 2:

Table 2 - Thematic meanings

Motor A-A - Point A Axial	Motor A-H - Point A Horizontal	Motor A-H Env - Point A Horizontal	Motor A-V - Point A Vertical
Motor B-A - Point B Axial	Motor B-H - Point B Horizontal	Motor B-H Env – Point B Horizontal Envelope	Motor B-V - Point B Vertical
Compressor C-A - Point A Axial	Compressor C-H - Point A Axial Horizontal	Compressor C-H Env – Point A Axial Horizontal Envelope	Compressor C-V - Point A Axial Vertical

The vibration values used in this study are in Root Mean Square (RMS). For the vibration limits, defined by the technical direction for this equipment, is considered 8 mm/s for the alert level and 12 mm/s for the alarm/critical vibrations.

To limit the study, only the most interesting results will be presented. And the most interesting results was to the compressor and not to the associated electric engine.

Application of QM Control Charts

The proposal of univariate short run control charts application to this data is an early study. The collect data was very few so we had to simulate data and the application of the chart was with 30 samples. We also have data in RMS values and an access to the frequency lecture for diagnose the type of anomaly, however, this will not be the object of this study.

Testing the application of QM control charts it was note it´s possible to develop air compressor condition monitoring with this methodology. We also try the original Q control chart to compare results.

The result of the application of the control charts Q for the Air compressor from the diesel engines room of ship 1 for C point horizontal component is on Fig. 4 and in Fig. 5 we can observe the modified Q chart with the same data.

Accordingly, the defined rules if it is considered the QM charts and the Q charts, non-modified, it is observed that both charts registered the need of inspection action on observation nr 11 and a maintenance on observation nr 6. By this results it should be only considered the maintenance need. But it is observed that for the original Q chart, it has higher values, and probably, if the collected data was continuous, it will induce to an early intervention without be really needed. So by now on only the QM charts will be applied because of it trustworthy.

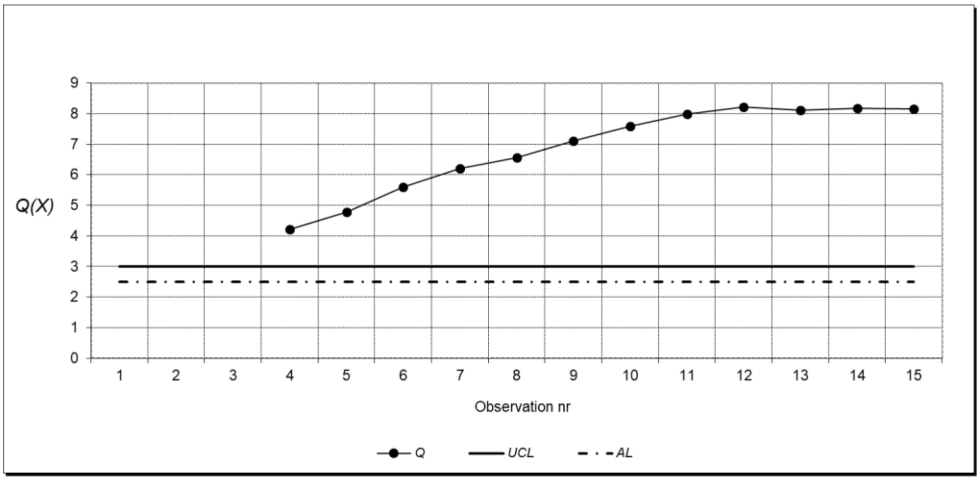

Fig. 4 - Q Chart – Results of Air compressor from engine Room horizontal observation (C-H Envelope) for ship nr 1

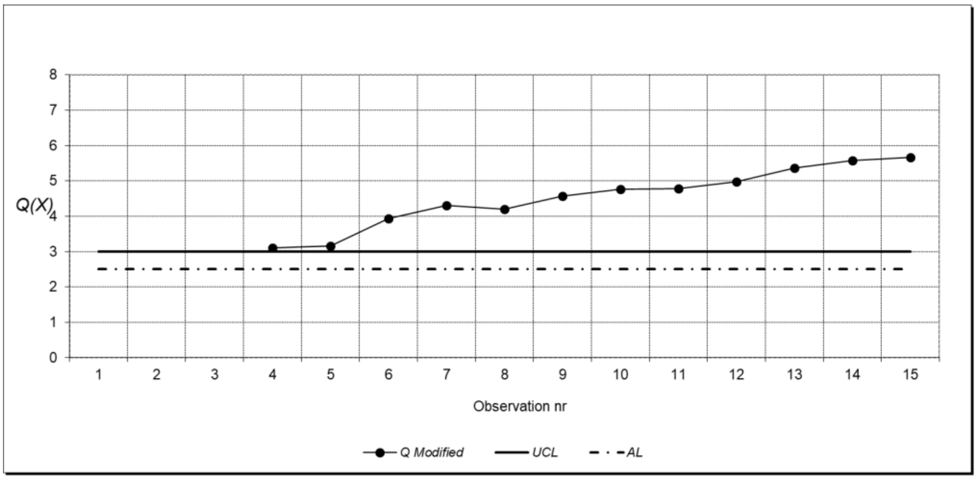

Fig. 5 - QM Chart –Results of Air compressor from engine Room horizontal observation (C-H Envelope) for ship nr 1

For axial component on point C the results for QM charts were only zero. For vertical component it was obtained the Fig. 6. On this figure it is observed that for the vertical component the vibration registered are higher than for the horizontal component.

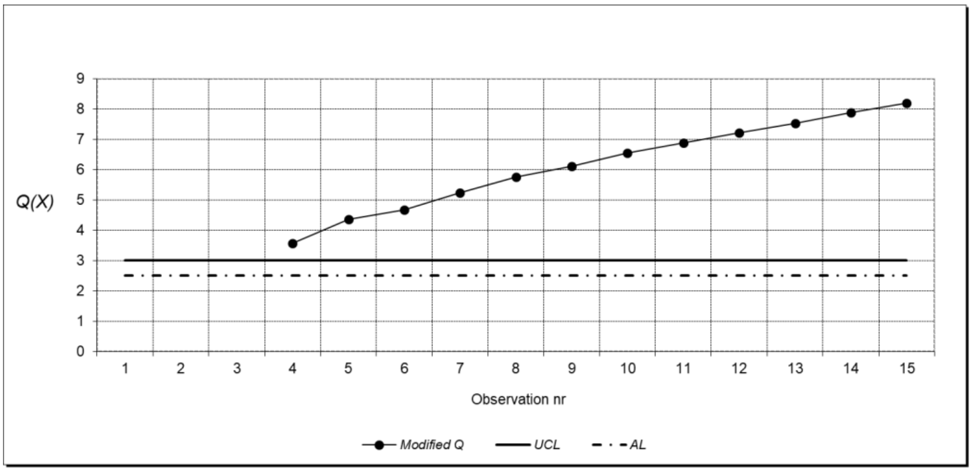

Fig. 6 - QM Chart –Results of Air compressor from engine Room horizontal observation (C-V) for ship nr 1

In the next figure, Fig. 7, we represent the values of the three compressors of the engine room from the three ships for point C-H, from a previous lecture and an actual lecture.

It is believed that the best comparison between this equipment's is from the same engine room because of eventual induced vibration from the ship structure and other equipment in the room.

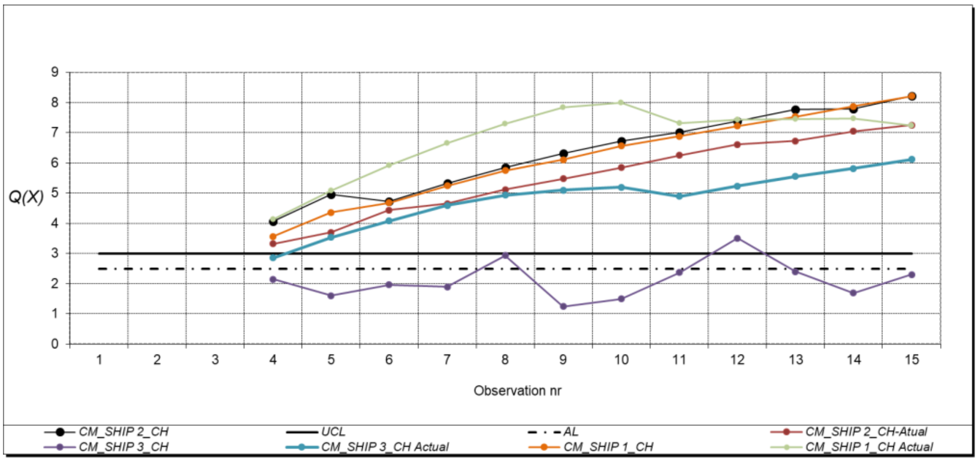

Fig. 7 – QM Chart –Results of Air compressor from engine Room horizontal observation (C-H)

The results on the previous figure represent the change needed on maintenance philosophy, the equipment should be monitored from the first time it starts functioning, although the ship nr 3 didn´t need an intervention of maintenance at than, now it needs a maintenance intervention since observation nr 7, and an inspection intervention on observation nr 12. All the others ship registered the need of maintenance before the inspection.

Although the obtained results, still considering the defined methodology, before the intervention it may be applied other non-destructive test and the confirmation of the collect conditions should take place.

CONCLUSIONS

Air compressor systems on ship play an important role in diesel engine start, and functioning control in various equipment and systems.

The QM control charts allow the monitoring since the 4 observation.

Due to the lack of data, it was decided to test the application of short run control charts to vibration data collected from the Low-pressure air compressors. It was possible to detect a real anomaly.

The obtained results for Q charts show an already failure tendency. If the data was continuously, collected may the anomaly tendency may be had early detection. The data collection should be continuous and since the beginning of equipment life cycle.

The results for the vertical component were more sensible than the horizontal and axial component.

At the expense of the Q charts, and don´t forgetting the need of more tests, it was considered adequate the application of *QM* charts on the performance control of the air compressor system.

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