UTILIZATION OF NEW DEFINITIONS TO CALCULATE OVERALL EQUIPMENT EFFECTIVENESS FOR AIR COMPRESSORS: A CASE STUDY

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Abstract - There are growing needs for energy in the 21st century, while as a part of sustainable development and environmental considerations, using energy resources wisely and responsibly is a great importance. In this regard, companies are moving towards new methods to put their machines to optimal working condition. Compressed air has been used in the industries for several years and it is one of the most expensive energy resources which is mainly produced by compressors, turning electricity to potential energy stored in compressed air. As this equipment showed its vital role in the different industries such as car manufacturing, it is necessary for managers to know how effective their equipment are working. Iran Khodro Company; the biggest car manufacturer in Iran and also in the Middle East, is not an exception. In many parts of this company like body shops, paint shops and press shops, compressed air that is produced by different types of air compressors is being used. Because of this, managers and other authorities need to know about their equipment effectiveness. In order to do that, engineers in this section faced some difficulties to find a way to calculate this factor. To demonstrate the technique, time interval has been limited between march to august of 2017 in terms of the number, timing and impact of downtime and efficiency of each Compressor Brigade for Iran Khodro Company will be performed in terms of the amount of compressed air produced in proportion to the energy consumption of a specific compressor using the calculation of the relevant indices. Effect of the efficiency of each compressor for the compressed air department of Iran Khodro in terms of the amount of compressed air and its energy consumption, as well as analysis based on the failure rates and their repairs and overhauls costs based on the calculation of relevant indicators such as PM Rate, Range Rate, Mean Time To Repair (MTTR), Mean Time Between Failures (MTBF), Mean Time To Failure (MTTF), Availability (AV), and finally the OEE (Overall Equipment Effectiveness) which is a Management Indicator. In this paper, the analysis of the compressors used in Tehran site of Iran Khodro Company in terms of efficiency and calculation of maintenance indicators, as well as management indicators such as OEE index have been introduced, as well as defining the term "Quality" in OEE calculation.

Keywords - Compressors Maintenance, Effective Planning, Equipment Health Assessment, Overall Equipment Effectiveness (OEE).

I. INTRODUCTION

Equipment analysis due to the variety in the operation of air compressors, such as centrifugal or screw type with different working pressures, and also the study of their operation since march to august of 2017 in terms of the number, timing and impact of downtime and efficiency of each Compressor Brigade for Iran Khodro Company will be performed in terms of the amount of compressed air produced in proportion to the energy consumption of a specific compressor using the calculation of the relevant indices.

Maintenance indexes have definite descriptions in all international references that will be used to compute them in this paper, but what matters is that for equipment with different definitions, the overall equipment efficiency (OEE) index can have different computational methods that can be found in This paper and have been computed for air compressors. Also, the technical information of the equipment that has been examined are discussed in detail.

OEE index is one of the management indexes that, along with other commonly used indexes in net science, including MTBF and MTTR can provide an accurate understanding of the state of equipment used in a company (including operational or standby state) and the Range of failure in them for managers. Unlike engineering and maintenance indexes which alone cannot be analyzed, OEE index is an analytical and managerial indicator. It is necessary to explain that in calculation of OEE index which has been calculated by the well-known formula shown in Equation (1), in the case of different equipment with expected performance, its parameters will be calculated differently [1-3].

$$\mathrm{OEE} = \mathrm{Av} * \mathrm{P} * \mathrm{Q} \quad (1)$$

The parameters in equation (1) are Availability, Performance and Quality, respectively. In this paper have been tried by studying the mentioned indices for compressors belonging to the department of production and distribution of compressed air in Iran Khodro Company, an analysis of equipment status can be demonstrated.

In this paper, the analysis of the compressors used by Tehran Iran Khodro Company in terms of efficiency and calculation of maintenance indicators, as well as

management indicators such as OEE index have been introduced, as well as compressors have been rejected in terms of quality.

II. INTRODUCTION OF COMPRESSED AIR DEPARTMENT

Iran Khodro Company as the largest car manufacturer in Iran and Middle East for the provision of compressed air for car production lines employs 50 air compressors in 7 and 10 bar pressure range which 38 compressors have been chosen as a case study. Since Iran Khodro is active in three working shifts and 24 hours a day, it is necessary that the working pressure of the production lines has been supplied constantly by the company's compressed air department at all working hours. The compressors of this department based on the requirements of production lines are divided into two groups, compressors to generate 7 and 10 bar pressure. Compressors information has been demonstrated below in table (I). These compressors are from popular companies such as Samsung, Ingersoll rand, Atlas Copco, CompAir and Pars which produce compressed air in standard and oil free (high) quality. Standard quality air is used in body shops, assembly shops and rims shops where a little oil in the compressed air will not cause problem or fault. Oil free or high quality air is used in paint shop to power robots which are painting the body of the car.

Compressor Number	Manufacturing date	Demanded quality	Working pressure (bar)
1	2015	Standard	7 bar
2	2015	Standard	7 bar
3	2015	Standard	7 bar
4	2002	Standard	7 bar
5	2005	Standard	7 bar
6	2015	Standard	7 bar
7	1980	Standard	7 bar
8	1981	Standard	7 bar
9	1982	Standard	7 bar
10	2009	Standard	7 bar
11	2009	Standard	7 bar
12	1996	Standard	7 bar
13	1996	Standard	7 bar
14	1995	Standard	7 bar
15	1998	Standard	7 bar
16	1976	Standard	7 bar
17	1976	Standard	7 bar
18	2009	Standard	7 bar

19	2009	High	7 bar
20	2009	High	7 bar
21	2009	High	7 bar
22	2009	High	7 bar
23	2009	High	7 bar
24	2009	High	7 bar
25	2003	High	7 bar
26	2001	High	7 bar
27	2001	High	7 bar
28	2001	Standard	10 bar
29	2001	Standard	10 bar
30	1973	High	10 bar
31	1973	High	10 bar
32	1973	Standard	7 bar
33	1983	High	8 bar
34	1985	High	9 bar
35	1971	High	10 bar
36	1983	Standard	10 bar
37	2000	Standard	10 bar
38	2000	Standard	10 bar

Table I. Compressors Information

As it is evident in the table (I), the compressors belong to the compressed air department are old but of course active which increases their failure rate. Therefore, in order to guarantee the continuity of energy, production lines a very precise maintenance and repair system are required.

III. METHODOLOGY

As shown in equation (1), OEE index is calculated from the product of the three factors. If we want to calculate the total OEE for the compressed air department, then we can assume that the values of the parameters except p have the value of 1. The value of p is reduced to 92 percent of its value due to the leakage measurement of the system, so for p, the value is 0.92, and according to equation (1), OEE with a value of 0.92 can be calculated, which according to the system conditions is reasonable.

Since in this paper, the computation and expression of compressors effectiveness are considered, we assume the system boundary as compressor itself. In this method, the calculation of the factor Q will have a value of 1. Because the point of measurement of the volumetric flow of air is just at the outlet of the compressor, which is located on the boundary and there is no rejected air at this point. On the other hand, various factors have to be considered in order to calculate the effectiveness of compressors. In fig. (1) the suggested approach to define factors has been demonstrated.

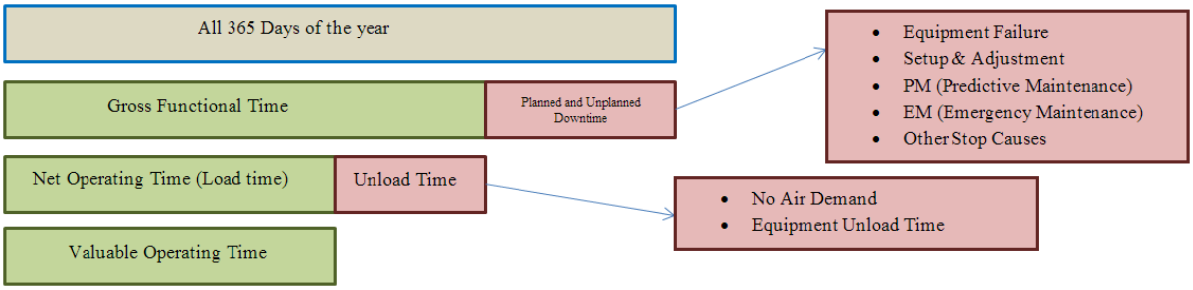


Fig. (1) Suggested Approach

It should be noted that in Iran Khodro's site, almost all of its production lines are operating 24 hours a day in three shifts. On the other hand, based on the market demand, it is necessary for production management to declare shifts in a number of production halls of the company at a number of scheduled holidays. Also, due to the fact that the distribution network of compressed air in Iran Khodro's site is continuous and there is no possibility of separating compressed air consumption of a hall, the process of producing and distributing compressed air is an uninterrupted process throughout the year. In the event of momentarily interruption of compressed air, some processes or equipment for production and support will be experiencing serious disturbance and damage. According to the above, in the calculations of the indices we have to consider the planned time as 365 days a year and 24 hour a day. In case of availability calculation, equation (2) is suggested to use for air compressors.

$$\text{Av} = \frac{(365\ \text{days of year} - \text{Downtimes})}{(365\ \text{days of years})} \qquad (2)$$

Planned and unplanned downtime include losses due to equipment failures, predictive maintenance, lack of spare parts, overheating, and any planned and unplanned causes that make the compressors not available to produce compressed air.

As shown in equation (3), the parameter P is result of the production time of a net output of an equipment to its entire availability time. In this paper, the net output of a compressor consists of the amount of compressed air produced by the compressor in a given time period in real working conditions. In other words, increasing the parameter P depends on the maximum production of compressed air of equipment during the entire time of its availability.

$$\text{P} = \frac{(\text{Load Time})}{(365\ \text{days of year} - \text{Downtimes})} \qquad (3)$$

The important thing to note here is that all references that are related to total productive maintenance have focused on taking the planned net time into consideration. This is because the Av index increases dramatically by eliminating unplanned times for the production of an equipment (production planned time which is in the denominator of the Av index). While by the explanation given in this article is inevitably limited to consider the maximum possible time for working hours of equipment. It is natural that in this situation, any operation of the device despite its availability, due to internal or external factors, will all negatively affect the parameter P. Since one of the purpose of this paper is to calculate OEE as close as possible to its real value. To do so it has been recommended to multiply it by capacity coefficient (equation (4)).

$$\text{Capacity Coefficient} = \frac{(\text{Actual Capacity})}{(\text{Nominal Capacity})} \qquad (4)$$

And by using equation (4), equation (5) can be achieved.

$$\text{P} = (\text{Eq. (4)}) * (\text{Eq. (3)}) \qquad (5)$$

Therefore by the explanations above, the suggested OEE equation to calculate for air compressors after simplification can be demonstrated as following equation(6).

$$\text{OEE} = \frac{(\text{Load time}) * (\text{Capacity Coefficient})}{(365\ \text{days of year})} \qquad (6)$$

Equation (6) has been resulted from putting equation (2), (5) and the value of quality which is one due to the mentioned reasons, into equation (1).

IV. RESULTS AND DISCUSSION

In this section all the data that are needed to investigate the status of equipment. The information of compressors that has been studied including manufacturing date, working pressure and quality of demanded compressed air are available in table (I). In this table demanded quality shows the criticality of compressed air quality produced by compressors in case of existence of oil in the compressed air. That actually is the reason of using oil free compressors to satisfy these demands. In table (I), it is demonstrated that most of the compressors have the age of at least 12 years.

In the table (II), data for calculating OEE index including planned working time of compressors which is six months, total downtimes, load time have been shown.

Compressor Number	Planned Time (hr)	Total Downtime (hr)	Load time (hr)
1	4464	55	3588
2	4464	55	3744
3	4464	55	3692
4	4464	60	1758
5	4464	55	1821
6	4464	45	1291
7	4464	45	1469
8	4464	2645	654
9	4464	45	1289
10	4464	2389	789
11	4464	45	795
12	4464	45.5	2002
13	4464	1849	941
14	4464	166	1377
15	4464	1540	927
16	4464	1040	1337
17	4464	62	3404
18	4464	55	1176
19	4464	55	2015
20	4464	1352	830
21	4464	224	1513
22	4464	55	2542
23	4464	1329	593
24	4464	947	1454
25	4464	56	2303
26	4464	1264.75	1686
27	4464	61	2337

28	4464	58	1190
29	4464	62	1278
30	4464	60.75	1496
31	4464	60	1495
32	4464	60	617
33	4464	2160	1082
34	4464	65	3059
35	4464	55	247
36	4464	59	1510
37	4464	206	1199
38	4464	89.5	1138

Table II. Required Data

Since the calculation of P factor needs computing capacity coefficient and to do so must extract nominal and actual capacity from table (III).

Compressor Number	Nominal Capacity(m^3/min)	Actual Capacity(m^3/min)
1	83	79
2	83	79
3	83	79
4	63	59
5	70	68
6	34	28
7	34	28
8	40	34
9	43	35
10	43	35
11	26	22
12	44	38
13	43	37
14	43	37

15	43	37
16	43	37
17	54	51
18	43	40
19	32	28
20	32	28
21	32	28
22	32	28
23	32	28
24	32	28
25	32	28
26	32	28
27	32	28
28	20	18
29	20	18
30	30	26
31	30	26
32	54	51
33	55	51
34	55	51
35	32	28
36	20	18
37	15	14
38	15	14

Table III. Nominal and Actual Capacity

Finally by using equations (2) to (6) and tables (I) to (III), OEE index and its factor can be achieved for mentioned equipment as following table (table (IV)).

Compressor Number	Av	P	OEE
1	0.99	0.77	0.76
2	0.99	0.81	0.80
3	0.99	0.80	0.79
4	0.99	0.37	0.36
5	0.99	0.40	0.39
6	0.99	0.24	0.23
7	0.99	0.27	0.26
8	0.41	0.31	0.12
9	0.99	0.24	0.23
10	0.46	0.31	0.14
11	0.99	0.15	0.14
12	0.99	0.39	0.38
13	0.59	0.31	0.18
14	0.96	0.28	0.27
15	0.66	0.27	0.18
16	0.77	0.34	0.26
17	0.99	0.73	0.72
18	0.99	0.25	0.24
19	0.99	0.40	0.39
20	0.70	0.23	0.16
21	0.95	0.31	0.30
22	0.99	0.50	0.49
23	0.70	0.17	0.12
24	0.79	0.36	0.29
25	0.99	0.46	0.45

26	0.72	0.46	0.33
27	0.99	0.46	0.45
28	0.99	0.24	0.23
29	0.99	0.26	0.25
30	0.99	0.29	0.28
31	0.99	0.29	0.28
32	0.99	0.13	0.12
33	0.52	0.44	0.22
34	0.99	0.64	0.63
35	0.99	0.05	0.04
36	0.99	0.31	0.30
37	0.95	0.26	0.25
38	0.98	0.24	0.23

Table IV. Final Results

As it is shown in table (IV), some of the OEE indexes are very low which to analyze and explain the reasons must compute other indicators such as MTTF and MTBF. Results have been shown in table (V). These indicators have been calculated by using equation (7) and (8).

$$\text{MTTF} = \frac{(\text{Planned time} - \text{Repair time})}{(\text{Number of failures})} \qquad (7)$$

$$\text{MTBF} = \frac{(\text{Planned time})}{(\text{Number of failures})} \qquad (8)$$

Compressor Number	MTTF (hr)	MTBF (hr)	Number of Failures
1	∞	∞	0
2	∞	∞	0
3	∞	∞	0
4	∞	∞	0
5	∞	∞	0
6	∞	∞	0
7	∞	∞	0
8	∞	∞	0
9	∞	∞	0
10	1060.00	2232.00	2
11	4464.00	4464.00	1

12	4463.50	4464.00	1
13	1330.00	2232.00	2
14	4343.00	4464.00	1
15	2964.00	4464.00	1
16	3464.00	4464.00	1
17	4462.00	4464.00	1
18	∞	∞	0
19	∞	∞	0
20	3167.00	4464.00	1
21	4295.00	4464.00	1
22	∞	∞	0
23	1595.00	2232.00	2
24	3572.00	4464.00	1
25	4463.00	4464.00	1

Table V. Analysis Required Data

Compressor Number	MTTF (hr)	MTBF (hr)	Number of Failures
26	1085.75	1488.00	3
27	2230.50	2232.00	2
28	∞	∞	0
29	∞	∞	0
30	2230.63	2232.00	2
31	4462.00	4464.00	1
32	∞	∞	0
33	∞	∞	0
34	2229.50	2232.00	2
35	4464.00	4464.00	1
36	1487.67	1488.00	3
37	4316.00	4464.00	1
38	2216.25	2232.00	2

Table V. Analysis Required Data (Cont.)

During the investigations and data collection, the number of failures and repair time of the compressors from March to august of 2017 have been showed in table 2. In this paper, compressors that have been studied have different OEE index that can be analyzed more accurately according to the MTTF and MTBF index. MTTF and MTBF indices are infinite when there is no failure during the time interval. When at least one breakdown leads to a stop, the most ideal condition is to fix the failure at the shortest possible time, in which case the MTTF will be close to the planned time, which can be equal to the MTBF index.

For example, Compressor number 1 to 3 have a planned working time of 4464 hours between march to agaust of 2017, but their run times were about 3,600 hours, considering that during this period they did not stop because of breakdowns or PMs. Therefore, they have a high AV index, and during this time compressors have been almost always on and on load. it must be taken into account that these equipment as shown in table (I) are not old, so their capacity coefficient has a high value. As a result, the OEE index is desirable. For Compressor No. 1, the only reason for the OEE index deviation can be related to the time that no air was demanded. The other examples are compressors number 4 to 9, which their operating times do not have stops because of CMs and EMs but the time to use the equipment was much less than the planned time Which means the most ideal MTTF and MTBF index and a lower value in OEE index. as it has been said earlier the low OEE is directly related to the low usage of the equipment.

Another example in compressor No. 36 as it can be seen in the table (II), the load time of the equipment is 1510 which is less than the planned time. it must be taken into account that during this time it has done approximately 2000 hours of RUN. The equipment has failed and its operation has stopped 3 times in the assumed time interval. Downtime of the equipment includes more than 1200 hours of repair time which has a very effective influence in MTBF and MTTF indices. it can be concluded that this equipment has low effectiveness and low performance and because of its age which is 35 years it can be said that this compressor is worn out and it should be replaced.

By the discussion above, it has been proven that proposed approach can be used to calculate and compare compressor conditions which lead to a great index to help managers make better decisions.

V. CONCLUSION

Compressors normally need to be active in a shift, and by defining a 24-hour shift for it, for the reasons given, they will have a maximum effectiveness of 33%, which is not due to their improper function. The results show that many compressors, despite their desirable availability and the possibility of continuous operation, have a very low P index due to the lack of compressed air demand, which only requires greater compressed air demand to increase. Of course by using other approach to significantly increase the P index for a specific equipment, must reduce P indexes in other compressors. In this case we will not have an analytical look at the equipment.

It also can be concluded that the compressed air produced by compressed air department of Iran Khodro Company is less than the air compressors capacity. Therefore, it is preferred that in this department because of having lower risks and of course less cost, equipment with higher capacity and younger age being used. by doing so, equipment that are more precise have being used as a reserve equipment, due to the fact that the number of equipment in this department does not necessarily require the simultaneous use of all equipment. This leads to a low value in OEE index for old compressors. It should also be noted that in some cases, such as Compressor No. 36, this low OEE is largely due to aging and improper performance of this type of equipment.

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