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Reliability and Maintenance of Motor Operated Valves, in the Romanian Natural Gas Compression and Distribution Stations

Iulian VLADUCA, Robert Andrei ISAC, Vicenţiu Liviu RINGHEANU, Emilian TOMA, Carmen PETRE, Ramona-Manuela STANCIUC, Daniela CONSTANTIN, Mirela-Letitia VASILE

Romanian Research and Development Institute for Gas Turbines COMOTI, Bucharest, Romania
Iulian Vladuca, iulian.vladuca@comoti.ro

Abstract. The work defines the philosophy of COMOTI – Romanian Research & Development Institute for Gas Turbines, in the predictability of intervention time in case of defects, respectively the reduction of the cost price of maintenance for its MOVs (Motor Operated Valves), used on its own equipments for natural gas compression, existing in the natural gas compression and distribution sites from Romania. In the present work, the emphasis is on operational reliability and mentability, which are capitalized on the basis of the results regarding the operating behavior, over a certain period of time, of a large number of identical types of MOVs, actually used by the beneficiaries.

Keywords. MOV's, natural gas compression, reliability and mentenance, predictability.

1. Introduction

The reliability of a system is always less than that of the weakest component. With each additional construction element, the reliability of the system decreases, so the risk of failure increases. The information regarding the reliability of the MOVs (Motor Operated Valves) used in the COMOTI's equipments for natural gas compression, is mainly obtained by following the behavior of the products in field operation. In the present paper, MOVs will be named electrical valves or simply valves. Statistical study is done by processing the information obtained from a certain number of elements. The number of elements thus chosen is called the selection volume. The larger the selection volume, the closer the statistical processing results are to reality. During the construction and maintenance of a significant number of compression stations, the main defects that appear in the main electrical drivers of the MOVs are identified that ones that are used for opening and closing the inlet and discharge pipes. The two chosed MOVs for study are size 3, called MOV 3, with max. torque of 270 Nm for the isolation valves from the gas inlet, and size 2, called MOV 2 with maximum actuation torque of max. 150 Nm, for the valves at the gas discharge pipe of the compression installation.

Several distribution laws can be used to describe reliability, of which we mention only two:

- Exponential distribution. It is applicable when the failure rate is constant, the reliability being in this case:

$$R(t) = e^{-\int \lambda(t)dt} \tag{1}$$

and it can be shown that [1]:

$$MTBF = \frac{1}{\lambda} \tag{2}$$

where: MTBF – Mean Time Between Failures, λ – failure rate, and R(t) is the reliability.

- Weibull distribution. It is used when the failure rate is variable (the periods of youth and old age). The general expression of reliability according to three parameters is in this case:

$$R(t) = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left[\frac{t-\gamma}{\eta}\right]^{\beta}} \tag{3}$$

where: $R(t) \geq 0$, $t \geq 0$ or $t = \gamma$, β is the shape parameter, η – scale parameter > 0, (η, β > 0), γ – position parameter ($-\infty < \gamma < +\infty$).

Over time, a certain irregularity of the breakdowns related to the distribution of the life span can be observed. Frequently, the location parameter γ is not used, and the value for this parameter can be set to zero. In this case, the equation reduces to the two-parameter Weibull distribution. There is also a form of Weibull distribution known as the one-parameter Weibull distribution not discussed in the present paper.

General expression of reliability as a function of two parameters, is in this case:

$$R(t) = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left[\frac{t}{\eta}\right]^{\beta}} \tag{4}$$

Mathematical description of the probability of failure, according to the Weibull distribution has the expression [2]:

$$F(t) = 1 - e^{-\left[\frac{t}{T}\right]^{b}} \tag{5}$$

where t is the statistical variable (operating time, number of actuations, load variations, etc.); T - characteristic lifetime (at t = T, F(t) = 63%); b - parameter that characterizes the failure slope).

For β = 1, the three-parameter Weibull Eq. (3) reduces to the two-parameter exponential distribution equation:

$$R(t) = \frac{1}{\eta} \cdot e^{-\frac{t-\gamma}{\eta}} \tag{6}$$

where:

$$\frac{1}{\eta} = \lambda = \text{ failure rate} \tag{7}$$

Statistical methodology of experimental data frequently uses the Weibull distribution as a statistical model. Depending on one, two or even three parameters, the Weibull distribution can model phenomena whose failure rate can be increasing or decreasing and can have very different shapes.

Information on the reliability of valves is mainly obtained either by observing the behavior of the products field operation or during tests. The statistical study is done by processing the information obtained from a certain number of elements. The number of elements thus chosen is called the selection volume. The larger the selection volume, the closer the statistical processing results are more accurate.

From the point of view of maintenance, it appeared as an industry term for the first time in the 1950s in the U.S. [3-5], later spreading to Europe, overlapping the terms maintenance and repair. Maintenance involves the choice of the means of tracking good operation, preventing breakdowns (which have as a consequence the cessation of good operation), remedying failures and restoring good operation (with the recording of all the stages completed). As a result, maintenance includes a complex of technical-organizational activities that also involve economic considerations and aim to achieve optimal good functioning. Maintenance starts with the conception of the product and goes through all the stages until it is finally taken out of service. The term maintainability also, appears and it represents the ability of a system, under given conditions of use, to be maintained or restored to the condition of performing its specified function, when maintenance and repairs are carried out under given conditions, with precise remedial procedures. So, maintainability is that qualitative characteristic of a system, viewed from the point of view of maintenance and repair. The maintainability function or time-repair function of a system, denoted by M(t), is the probability of full restoration of system functions at time t.

$$M(t)= P\ (T < t) \tag{8}$$

where, M(t) - represents the probability that the system repair is completed in the interval (0, t).

The term availability is also defined, which can be defined as the ability of a system or a component of the system to fulfill its required function under the compatible aspects of reliability, maintainability and organization of maintenance operations at a time t, or in a time interval Δt. *The availability coefficient* (proportion of active time), [6], or intrinsic availability is defined by the formula:

$$K_A = \frac{MTBF}{MTBF+MTTR} \tag{9}$$

The unavailability coefficient (proportion of idle time) is given by the formula:

$$K_{IN} = 1 - K_A = \frac{MTTR}{MTBF+MTTR} \tag{10}$$

The unavailability coefficient has a constant value, independent of time and represents the proportion of idle time (system shutdown). The proportion of availability is defined by the ratio:

$$K_D = \frac{MTTR}{MTBF} \tag{11}$$

2. Model description

During construction and maintenance of the significant number of compression stations, by the COMOTI – Romanian Research & Development Institute for Gas Turbines, the main defects that appear in the main electrical drives for closing the inlet and discharge valves, were identified. The two sizes are of the size 3, called MOV 3, with max. 270 Nm for the isolation valves from the gas inlet, and size 2, called MOV 2 with maximum actuation torque of max. 150 Nm, for the isolation valves at the discharge as follows in table 1 below. Type 3 with a maximum torque of 270 Nm was chosen for the range of existing DN150 ÷ DN200 inlet valves, and type 2 with a maximum torque of 150 Nm was chosen for the range of existing DN80 ÷ DN100 valves at gas discharge. The the two valve types, called MOV 3 and MOV 2, used in 41 compression equipments used in the natural gas compression and distribution parks from Romania, have been observed from the failure point of view and the date are shown in the table 1. The are two types of compression installations installed in the operated parks:

- Compression installations for low pressure: inlet <5 bar and discharge ≤ 16 bar
- Compression installations for high pressure: inlet ≥5 bar and discharge >16 bar

In table 1, have been shown for both types of valves, at inlet and discharge, the record of the failures for a total of 7 years (about 61,320 hours) in the operated sites.

Table 1. Failure analysis for compression equipments produced by INCD Turbomoare COMOTI in an average of 7 years in the operational parks (61,320 hours)

No.	Gas compression and distribution site	Compressor type	Inlet valve	Discharge valve
1.	Site 1	Low pressure	2	1
2.		Low pressure	2	0
3.		Low pressure	2	0
4.		High pressure	4	0
5.		High pressure	3	2
6.		High pressure	3	3

Table 1. Failure analysis for compression equipments produced by INCD Turbomoare COMOTI in an average of 7 years in the operational parks (61,320 hours) (continued)

No.	Gas compression and distribution site	Compressor type	Inlet valve	Discharge valve
7.	Site 2	Low pressure	1	1
8.		Low pressure	2	1
9.		Low pressure	2	1
10.		Low pressure	3	0
11.		High pressure	2	0
12.		High pressure	3	0
13.	Site 3	Low pressure	3	1
14.	Site 4	High pressure	2	1
15.		High pressure	3	1
16.		Low pressure	1	1
17.		Low pressure	3	0
18.		High pressure	3	2
19.		High pressure	5	1
20.	Site 5	Low pressure	1	0
21.		Low pressure	1	1
22.		High pressure	3	1
23.		High pressure	2	0
24.		Low pressure	4	2
25.		Low pressure	3	0
26.		High pressure	2	1
27.		High pressure	3	3
28.	Site 6	Low pressure	2	1
29.		Low pressure	5	2
30.	Site 7	High pressure	3	1
31.		High pressure	5	2
32.		High pressure	1	0
33.	Site 8	High pressure	1	1
34.		High pressure	0	2
35.	Site 9	Low pressure	1	1
36.		Low pressure	3	2
37.	Site10	Low pressure	2	1
38.		Low pressure	1	0
39.		Low pressure	2	1
40.	Site 11	Low pressure	1	2
41.		Low pressure	3	1

It is assumed that the type of electrical valves on the inlet and outlet pressure are of the same type, from the same distributor. In table 2 were grouped number of failures/valve type over a 7-year average.

Table 2. Grouping of defects in the electric drives of isolation valves, in an average of 7 years of operation (61,320 hours).

Valve type	No. of valves	No. of failures/61,320 hours
Valve for low inlet pressure < 5 bar	21	45
Valve for low pressure discharge ≤ 16 bar	21	18
Valve for high inlet pressure ≥5 bar	18	44
Valve for high pressure discharge >16 bar	18	20

With help of the average time of good operation, the periodicity of inspections can be established, as part of preventive maintenance, so that they take place shortly before the appearance of defects.

$$T = k \cdot MTBF \tag{12}$$

where k is an economic parameter; for small values of this, the residual corrective maintenance is lower, so the interventions are more frequent, which causes the direct costs increase. In [1], to avoid waste, the residual corrective maintenance threshold will have values between 5 and 10% as indicated.

The failure rate can be expressed as the probability that the failure occurs in a specified time, without any failure occurring until time t, and can be described statistically by the equation:

$$\lambda = \frac{n}{N \cdot \Delta t} \tag{13}$$

where n is the number of elements that failed in the performance investigation interval Δt; N - total number of elements. The reliability of a system is always less than that of the weakest component. With each additional construction element, the reliability of the system decreases, so the risk of failure increases.

We assume exponential modeling with β=1 and γ=0.

Mean MTBF times can be calculated with the relation (14), see Eq. (2):

$$MTBF = \frac{1}{\lambda} = \frac{N \cdot \Delta t}{n} \tag{14}$$

where n is the number of elements that failed in the performance investigation interval Δt; N – total number of elements.

Failure rate:

$$\lambda = \frac{1}{MTBF} \tag{15}$$

The probability that an actuation will not fail in a time t (probability of being operational), is given by the relation:

$$P(t) = e^{-\frac{t}{MTBF}} \tag{16}$$

In table 3, were grouped the MTBF calculation, failure rate and the probability that an equipment will be in operation after 3000 hours, according to the beneficiary's specifications.

Table 3. MTBF, failure rate and probability of an equipment being in operation after 3000 hours.

Valve type	MTBF (hours/failure)	Failure rate-λ	P(t) at 3000 hours
Valve for low inlet pressure < 5 bar	$\frac{21\cdot61320}{45}$=28616	$3.49\cdot10^{-5}$	90%
Valve for low pressure discharge ≤ 16 bar	$\frac{21\cdot61320}{18}$=71540	$1.39\cdot10^{-5}$	95.9%
Valve for high inlet pressure ≥ 5 bar	$\frac{18\cdot61320}{44}$=25085	$3.98\cdot10^{-5}$	88.7%
Valve for high pressure discharge >16 bar	$\frac{18\cdot61320}{20}$=55188	$1.81\cdot10^{-5}$	94.7%

Thus, in 3000 hours the number of valves that could be changed for repair out of the total of 82 valves from the 41 installed installations is shown in the table 4:

Table 4. No. of valves that could be changed in 3000 hours of operation.

Valve type	No. of possibly faulted valves after 3000 hours
Valve for low inlet pressure < 5 bar (Type 3)	2
Valve for low pressure discharge ≤ 16 bar (Type 2)	1
Valve for high inlet pressure ≥ 5 bar (Type 3)	2
Valve for high pressure discharge >16 bar (Type 2)	1

A higher probability of failure is observed for the size 3 with an actuation torque of 270 Nm, compared to size 2 with an actuation torque of 150 Nm. Statistically, considering that the electric motor of the drive present 80% of the failure percentage of the drive, it is concluded that the main factor of the failures is the power load peaks required to close and open the valves.

For a valve with a well-defined operation, whose reliability is known, and whose availability is to be optimized through maintenance actions, it is found that its maintenance can be influenced both at the design level and in operation (through the maintenance policy). One of the chosen methods is that of predictive maintenance (PdM) [7] - that is a new concept that even eliminates some of the shortcomings introduced, through repeated interventions on products or their component elements, checking the status of the system by on-line advanced techniques, and for very important systems even by permanent monitoring. The personnel and material base, necessary for these actions, constitute the maintenance support.

In Fig. 1, the logic diagram for the repair of a valve in an operating compression site, with COMOTI's compressors is given.

Six possible situations have been identified for repairing the valve:

- The part breaks down - it is ordered from COMOTI - it exists as a spare part in the COMOTI warehouse - the part is replaced by the site operational personnel
- The part breaks down - it is ordered from COMOTI - it exists as a spare part in the COMOTI warehouse - the part is replaced by the COMOTI team
- The part breaks down - ordered from COMOTI - the part does not exist in the COMOTI warehouse - the part is ordered from the beneficiary - the part is in stock - the part is sent to COMOTI - the part is replaced by the beneficiary team
- The part breaks down - ordered from COMOTI - the part does not exist in the COMOTI warehouse - the part is ordered from the beneficiary - the part is in stock - the part is sent to COMOTI - the part is replaced by the COMOTI team
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- The part breaks down - ordered from COMOTI - the part does not exist in the COMOTI warehouse - the part is ordered from the beneficiary - the part is not in stock - the part is sent to COMOTI - the part is replaced by the COMOTI team.

Nine operations have been identified to repair the actuation according to the 6 possible situations listed above, see also, the Fig. 1.

Losses recorded by compressor standby are given by:

$$P_{st}=P_{pg} + S_{op} \tag{17}$$

$$P_{pg} = D_{gp} \times C_{gp} \tag{18}$$

where: P_{st} = losses due to stationarity, P_{pg} = gas pumping losses, D_{gp} = pumped gas flow rate, C_{gp} = pumped gas cost, S_{op} = station operator salaries

Since the maximum downtime is given by the purchase of the equipment if it is not in the supplier's stock, the cost of salaries of the operational personnel can be neglected compared to the cost of gas pumped into the network. For the calculation of gas pumping losses, we consider the pumped flow of the plant of 60,000 Nm^3/day.

The average price of gas delivered in conformity with the Romanian Centralized Market, from OMV Petrom Capital Market Story – February 2024 [8] in the quarter 4 of 2023, was (without taxes) 38 RON/MWh or 244.4€/1000Nm^3 [9]. For each stationary day the P_{pg} (losses given by not pumping in (€)) will be:

$$\boldsymbol{P_{pg} = 60,000Nm^3/day \cdot 0.2444€/Nm^3 = 14,664€/\mathrm{day}} \tag{19}$$

Table 5 shows the losses according to the identified operation and the operating time:

Table 5. Losses according to the identified operation and operating time

Operation (Op)	Operating time (Days)	P_{pg} (losses for not pumping) (€)
1	3	43,992
2	1	14,664
3	1	14,664
4	2	29,328
5	2	29,328
6	5	73,320
7	10	146,640
8	60	879,840
9	2	29,328

Thus, for six possible situations of electrical actuation repair, we have, according to the graph, in table 6, the losses in an operated park with the repair of the solenoid valve in which the travel costs of COMOTI personnel and the operating costs of beneficiary were neglected.

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Table 6. Repair times and losses depending on the electrical valve repair route

Valve replacement route	The operation routes	Total operating time T_{op} (days)	Losses (€)
1	Op1+Op2+Op3+Op4	7	102,648
2	Op1+Op2+Op3+Op5	7	102,648
3	Op1+Op2+Op6+Op7+Op9+Op4	23	337,272
4	Op1+Op2+Op6+Op7+Op9+Op5	23	337,272
5	Op1+Op2+Op6+Op8+Op9+Op4	73	1,070,472
6	Op1+Op2+Op6+Op8+Op9+Op5	73	1,070,472

Average Time to Repair MTTR is:

$$MTTR = \sum_{i=1}^{6} \frac{T_{op}}{N} = 34.3 \tag{20}$$

where, N = number of possible routes.

Thus MTTR = 34.3 days = 823 hours. The average stationary losses will be Pst = 502,975.2 (€). The following coefficients can be calculated using table 3 and table 6:

- Availability coefficient: KA (proportion of idle time), see Eq. (9)
- The unavailability coefficient: KIN (proportion of idle time), see Eq. (10)
- Availability proportion: KD, see Eq. (11)

Table 7 lists the respective values for the isolation valves studied.

Table 7. Values of the coefficients of availability, unavailability and the proportion of availability

Valve type	KA	KIN	KD
Valve for low inlet pressure < 5 bar	0.972	0.028	0.0288
Valve for low pressure discharge ≤ 16 bar	0.988	0.012	0.0115
Valve for high inlet pressure ≥ 5 bar	0.968	0.032	0.0328
Valve for high pressure discharge >16 bar	0.985	0.015	0.0149

In the Fig. 1 below, it is shown the Logic Diagram for replacing a failured valve.

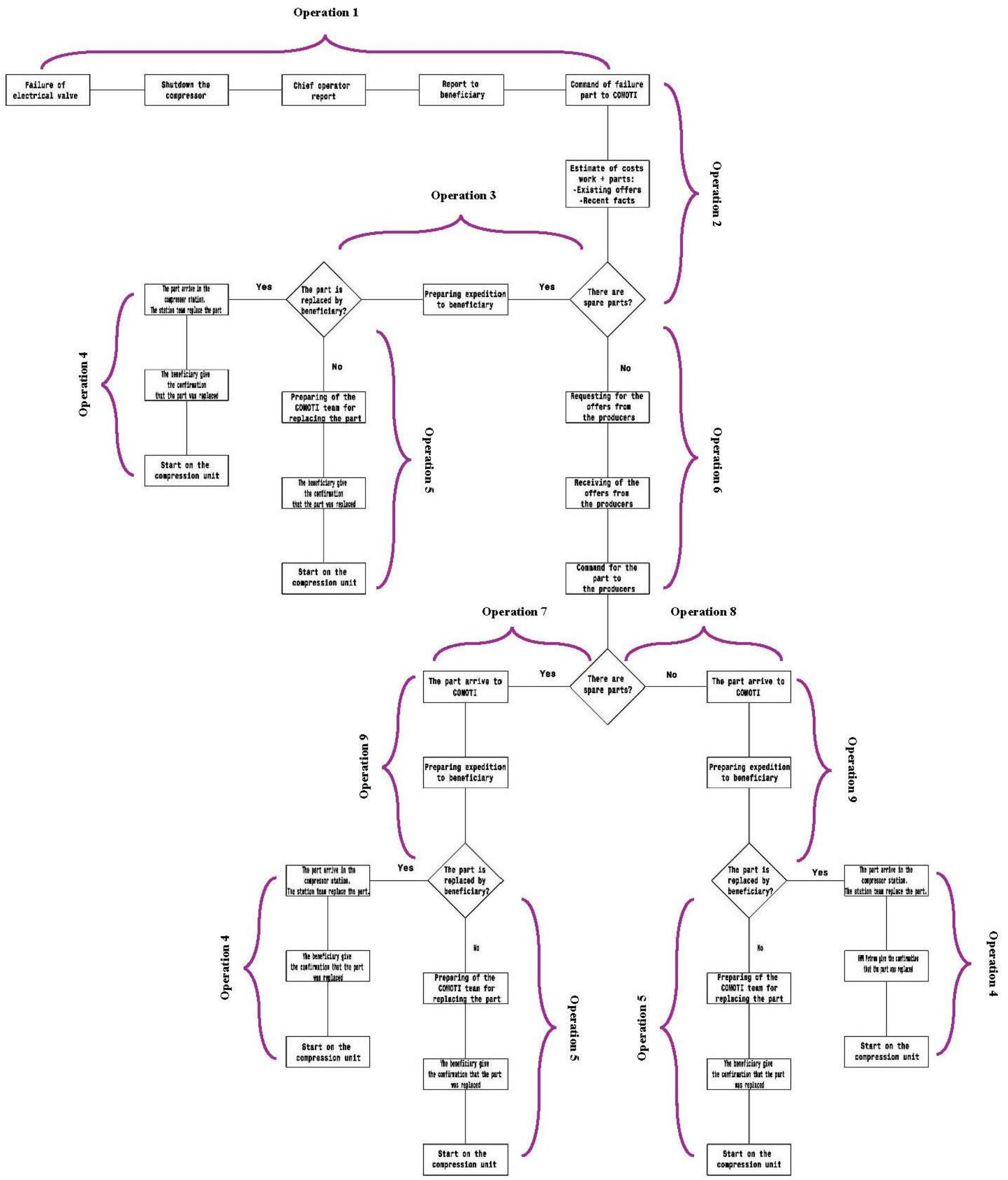

Figure 1. Logic diagram for replacing an electric drive

3. Conclusions

The present paper analyzes the possibility of reducing maintenance costs the screw compression equipment that COMOTI produces and has in operation in different gas pumping sites. The analysis of the defects related to the instruments in the equipment automation system highlighted which are the critical components, the MTBF value for each of them and the factors that led to the appearance of the defects. The mandatory operating requirements that the electrical valves must comply with, have been identified, so, that they meet the specific working conditions in exceptional conditions but are harmonized with EU rules, API and other philosophies in the gas compression field.

Reliability R(t) is the probability that a product will work without failure in the interval (0,t) under determined conditions. In order to determine the ways of increasing the reliability of the electrical actuations of the valves, in the gas circuits, it is necessary to know the factors that influence the reliability, to analyze the causes of the failures and to quantitatively evaluate the reliability. Wear, corrosion, etc. studies mainly use the Weibull distribution as a statistical model.

The necessity for a method of predictive maintenance (PdM), is given by the high level of the costs for replacing a failured valve (in our case) in an operational park for natural gas compression and distribution. The calculations from above give a real situation of losses (~500,000 €) of the beneficiary in a case that are not supplied in a real time and replaced the failured valves, and this is a common failure with a probability of 2…3 valves at 100 (82 in our case), in 3000 hours of continuous functioning. The investment to buy a new valve and have it in stock is not high (~5000…8000 €/valve) and saves a large part of money produced by beneficiary and the investition for 3 valves for example represent just 3…5% from total losses of the beneficiary.

Future research will be carried out on larger experimental data and on other key elements from the compression installations.

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