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A Predicted Method of the Limit Vacuum Opportunity to Pump Vacuum of Big Vessel

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Abstract: This paper aims at a method's research of the item of the time of limitation vacuum degree in pumping vacuum of big vessel. The relation of time constant and limitation vacuum degree was researched by analyzing the dynamic variation rule in pumped vacuum process. The time of limitation Vacuum degree was obtained by least square method linear regression for vacuum degree dynamic variation data, and then the time of limitation vacuum degree was achieved. On account of that method, a software obtained the time constant of limitation vacuum degree was developed, and the forecast of limitation vacuum degree time has been realized. At last, this method was tested and verified in a project application. The result indicated that this method was very reasonable to acquire the time of limitation vacuum, and was consistent with theoretical analysis. So the method could provide some theoretical direction and has definite worth of engineered application.

1. Introduction

Vacuum is a widely used method in the fields of vacuum technology, aerospace, industrial production, food packaging and sealing detection [1-3]. In the vacuum process of Big Vessel vacuum system, when the system pumping capacity is poor, it often takes a long time to vacuum the system cavity. Especially for some large volume cavity equipment, it is very difficult to reach the limit vacuum when the vacuum is pumped [4]. And when it is impossible to increase the system pumping speed, in order to reach the predetermined limit vacuum, it must undergo a dynamic process of waiting for the vacuum degree to drop. In this process, if the worker can know in advance the ultimate vacuum arrival time, other tasks can be processed in parallel during the waiting process. When the scheduled vacuum timing is reached, the corresponding work is carried out again without waiting for a long time. It does not require time for the vacuuming process. In this paper, the method of predicting the ultimate vacuum in large vacuum pumping process is studied. The dynamic change law of vacuum pumping is analyzed, and the arrival time of ultimate vacuum is studied. On this basis, this paper has realized the method of predicting the ultimate vacuum timing and provided certain technical guidance for the operators in the vacuum process.

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2. The Law Analysis of Vacuum Pumping Dynamic Change

The vacuum process is the transfer process of the macroscopic amount of gas in the vacuum system in the uneven distribution and non-equilibrium state of the space. In this state, there will be a variety of gas migration, such as momentum transfer, energy migration and mass migration, until the new equilibrium state position is reached, that is, to reach the limit of the vacuum system [5].

In the vacuum process, the vacuum chamber gas is discharged through the vacuum pump through the system pipeline. The gas flows in the vacuum chamber for unsteady turbulent flow. The vacuum degree of vacuum environment is affected by the pump speed and efficiency, the free volume of vacuum chamber and the amount of leakage. When the pressure of the vacuum chamber is close to the ultimate pressure force, the change of pressure in the vacuum chamber is about zero [6]. From the above analysis, the pressure change of the vacuum vessel is as follows: without taking into account the leakage and the material discharge, the variation relationship between time is:

$$P = P_0 e^{-\frac{S}{V}t} \tag{1}$$

In formula (1):

P——vacuum degree, *Pa*;

P_0—atmospheric pressure, *Pa*;

S——Vacuum system pumping speed, *L/s*;

V—volume, *V*.

It can be seen from the formula that the change rate of vacuum degree is related to the pumping speed and volume of the system. The higher the pumping speed is, the faster the vacuum degree decreases. The larger the vacuum system volume, the slower the vacuum degree drops. In formula (1), let $\tau = V/S_{He}$ be the system reaction time constant. When t reaches 1 time constant ($t=\tau$), the vacuum degree is 36.8% [5](ie, $0.368P_0$) of the initial value; when t reaches 3 times the time constant, the vacuum degree is 5% of the initial value; when t Achieve 5 times the time constant, the vacuum is 1% of the initial value, has basically reached the ultimate vacuum. It can be seen that when t is $t \to \infty$, the vacuum degree reaches the ultimate limit vacuum, which is also the minimum value. The vacuum limit vacuum should be after the system 5 times reaction time. The dynamic curve of vacuum degree is shown in Figure 1.

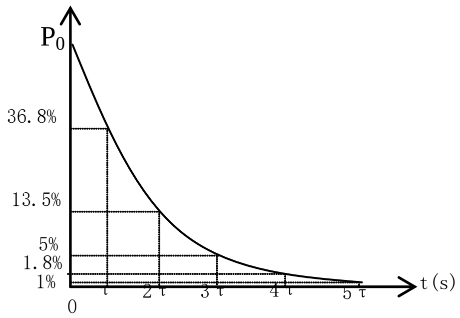

Figure.1 Graph of vacuum during vacuum pumping

3. Extreme Vacuum Timing Research to Acquiring Method

The above analysis shows that the degree of vacuum drop in the vacuum depends on the system reaction time constant τ. In the large-volume vacuum pumping, V is relatively large, resulting in a large time constant and a slower drop in the vacuum; but in a long time In the process of vacuuming, the timing of the ultimate vacuum can be predicted by finding the time constant. According to the constant formula $\tau = V/S_{He}$, finding the τ requires a known leak detection system volume and the pumping speed of the helium. For a system, these two parameters are often difficult to obtain accurately, especially the actual pumping speed. For this purpose, the data of the dynamic change of the vacuum degree with time during the vacuuming process can be used for analysis, and the research is conducted according to the variation rule of the vacuum degree data over time. The time constant of the vacuum system can be obtained by performing linear regression analysis on the local data of the vacuum change over time.

For both sides of formula (1), we take the logarithm of e at the same time.

$$\ln p = \ln P_0 - Bt \tag{2}$$

According to the principle of least squares, the values of intercept LnP_0 and slope B in formula (2) should minimize the sum of squared residuals of the predicted value of the regression line and the observed value, even if formula (2) has a minimum value. The tipi (i=1,2,3,4,5...n) is the time-varying data of vacuum for a group of consecutive same time intervals, to command that:

$$S_E^2 = \sum_{i=1}^{n} (\ln p_i - \ln p_0 + Bt_i)^2 \tag{3}$$

According to the extremum principle, to command that:

$$\begin{cases} \dfrac{\partial S_E^2}{\partial \ln P_0} = -2\sum_{i=1}^{n} (\ln p_i - \ln p_0 + Bt_i) = 0 \\ \dfrac{\partial S_E^2}{\partial B} = 2\sum_{i=1}^{n} t_i (\ln p_i - \ln p_0 + Bt_i) = 0 \end{cases} \tag{4}$$

This equation Can be solved, it has be gain that:

$$B = \frac{-\sum_{i=1}^{n} (t_i - \bar{t})(\ln p_i - \overline{\ln p})}{\sum_{i=1}^{n} (t_i - \bar{t})^2} \tag{5}$$

4. Realization and Application of Forecasting Method

According to the formula (5), the vacuum time constant acquisition software is compiled. In software programming, linear regression is carried out for the object with the continuous gain of vacuum degree with time changing data. Considering that the more sampling element points are selected by linear regression, the higher the precision of the fitting, the more the selected data element points are. Some of the main implementation algorithms of software writing are as follows:

```
Function Const-Time();
Var
averT ,averY: single;
sum1,sum2,sum3,B,ra :single;
z                :integer;
begin
timer3.Enabled:=true;
while (count<=N) and (stpp) do
begin
Application.ProcessMessages;
if not(timer3.Enabled) then
stpp:=false;
end;
```

```
if (count>N) then
begin
label14.Caption:='Being processed data......';
for z:=1 to N do
begin
sum1:=sum1+(z*r-averT)*(ln(comp[z])-averY);
sum2:=sum2+sqr(z*r-averT);
sum3:=sum3+sqr(ln(comp[z])-averY);
end;
B:=sum1/sum2;
B:=-1/B;
Edit6.Text:=FloatToStr(B);
end;。
```

In a project, a vacuum sealing tank with a volume of about $2m^3$ is needed, and the vacuum system adopts a combined vacuum pump with three total pumping speeds of 44L/s for overall pumping, as shown in Figure 2. According to the practical application of the project, the time constant of vacuum reaction is obtained by using the above method, and then the time of the limit vacuum of the vacuum system is analyzed.

Fig. 2 Vacuum system diagram

In the vacuum process, the vacuum meter is used to measure and record the change of the vacuum degree in the cavity, and the data of the change of the Vacuum degree over time in the vacuum process is measured as shown in table 1.

Table 1. Vacuum degree data change with time

Relative time(min)	vacuum degree(Pa)	Relative time(min)	vacuum degree(Pa)
0	55	35	25
5	43	45	23
10	36	55	22
15	32	63	21
20	30	72	20
25	28		

The above data are imported into the reaction time constant of vacuum pumping to obtain the calculation software. The time constant of vacuum system can be calculated by software, and the vacuum reaction time constant of this system is 14 minutes. Therefore, it can be predicted that this vacuum system must be 70 minutes after the vacuum degree can reach the limit vacuum. Finally, the variation curves of the system vacuum degree with time are described by using Table 1 data, as shown in Figure 3.

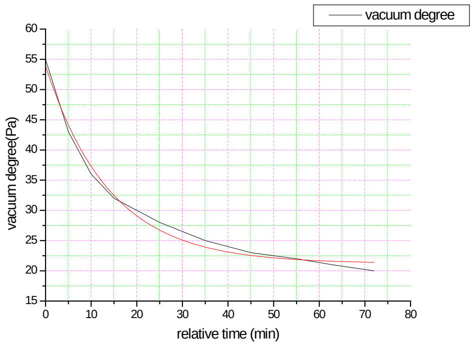

Fig. 3 The curve of Vacuum degree variation

As can be seen from fig. 3, the curve tends to be smooth after 70 minutes, and the vacuum degree changes very little. That is, after 5 times the reaction time constant, the stable state is basically reached. In the stable state, the vacuum degree of the system is close to the limit vacuum. From Fig. 3, the variation law of the measured data curve is basically in agreement with the theoretical analysis.

5. Conclusion

Based on the theory analysis of Vacuum degree dynamic change law of vacuum system, in this paper, the limit vacuum timing prediction Method of vacuum system is studied, the principle of least squares is used, the vacuum degree data in vacuum process is linear regression, the dynamic reaction time constant of vacuum degree of vacuum system can be calculated, so as to predict the time of limit vacuum. By compiling calculation software, the reaction time of vacuum system can be obtained by using the change data of vacuum degree, and the prediction of the limit vacuum time is realized. At last, combined with practical engineering application, the time constant of vacuum system is obtained by using this method, and the limit vacuum stability time of the system is predicted, and the correctness of this method is verified by the process of vacuum tank vacuum pump with volume about $2m^3$. This method provides a feasible scheme for predicting the time limit vacuum in the vacuum process of large volume vacuum system, which can guide the vacuum system.

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