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WEAR MODEL FOR PNEUMATIC JACKS AND MECHANICAL COMPONENTS

P. Lyonnet
UMR 5513, Ecole Nationale d'Ingénieurs de St. Etienne
42023 Saint-Etienne, France

Abstract: This article deals with the construction of a pneumatic test bench which has designed to experiment and validate the implementation theory of acceleration wear on pneumatic components. This theory is based on Cox model which is used to find acceleration parameters. The considered principle is raising of constraint of use in comparison with the test. Obviously, this raising of constraint should not distorted the states of failing. The use up which is the major parameter to be analysed is evaluated from the oil leak result.
Keywords: Jack Wear, Reliability , Acceleration test, Cox model

1 INTRODUCTION

The aim of our pneumatic test bench experimentation is to validate the method and theory for test acceleration based on stress increase compared to normal operating conditions has been developed as well as the method to calculate acceleration parameters. A software has been developed to validate this theory and modelling; what remains to be done is real life verification on a test bench, which is the goal of our presentation.

2 WEAR MEASUREMENT

Wear estimation is not carried out directly, but measured by the leak level on various fundamental points of the jack. This is estimated by the external leak rate on the rod and the leak rate on the piston (Fig. 1).

2.1 Leak measurement

Calculation of the quantity of material in chamber under pressure at a given moment with: $n = P.V / R.T$; P = Pressure; V = chamber volume; R = perfect gas constant; T = temperature; V_M = molard volum = 24.055 1 at 1.013 bars and 20° C; 65**%** of relative humidity; $ÄQ=(n_2-n_1)V_M/Ät$.

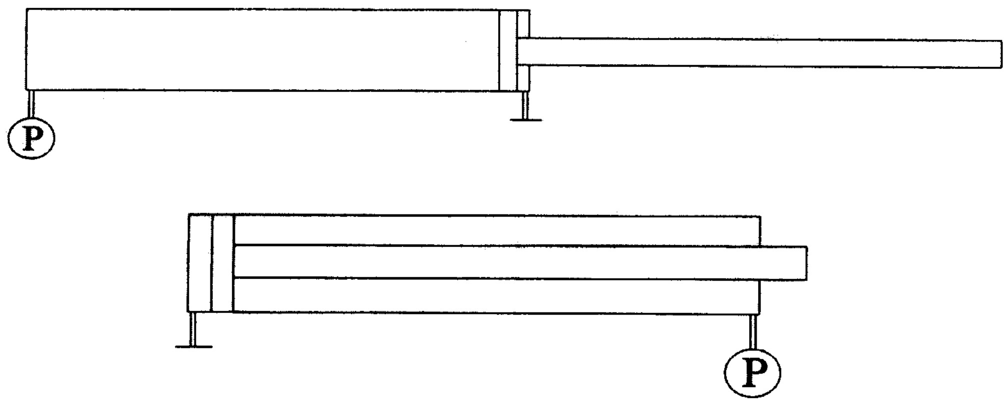

Figure 1. Pneumatic jacks

2.2 Test bench design

Once the factors to be accelerated (increase comparated to normal operating conditions) have been selected, what remains to be done is the definition of bench. The accelerated factors selected are: test pressure, fluid temperature, ambient temperature, cycle frequency. The bench must be capable of testing components simultaneously.

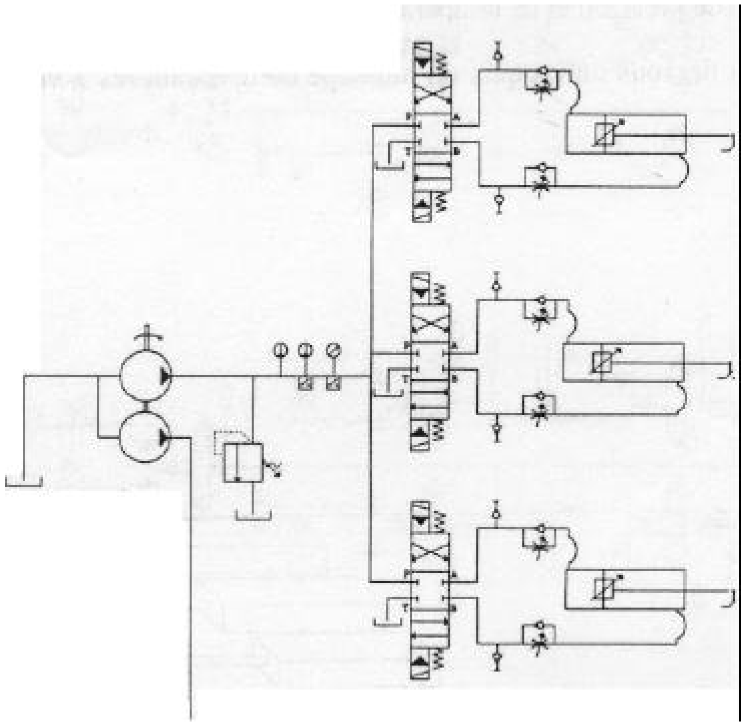

Figure 2. Test bench

3 MATHEMATIC'S AND "COX MODEL"

The Cox model determines a semi-parametric relation between the environmental factors, which are also called failure risk factors, and the life times distribution. This method is principally based on the proportional risks hypothesis which supposes that each factor influences the component's life time invariably during the test.

Regression models for survival datas can be written in the form of a reliability function depending on the time ë$_0$(t) determined in given environmental conditions and a function g(Z) of the environmental vector Z.

$$l\,(t,Z) = l_0(t) \cdot g(Z) \qquad (1)$$

The ratio of instantaneous risks does not depend on time, but only on environmental factors value Z_i and Z_j:

$$l\,(t,Z_i)\,/\,l\,(t,Z_j) = g(Z_i)\,/\,g(Z_j) \qquad (2)$$

So, the instantaneous risks are said proportional. Cox suggested to take the exponential model like environmental function. Moreover, this model is a multiplicative one in so far as the instantaneous risk of failure is multiplied by a constant when the value of an environmental factor Z_i is exchanged.

$$l\,(t,Z) = l_0(t) \cdot e^{\sum b_i . Z_i} \qquad (3)$$

with b_i influence of the environmental factor Z_i.

There also exist additive models like $l\,(t,Z) = l_0(t) + b_i . Z_i$, but they are less frequently used. Indeed, Cox model presents the advantages to ensure the positivity of the instantaneous risks and not to make hypotheses on the form of the function $l_0(t)$.

The instantaneous risk ratio is:

$$l\,(t,Z_i)\,/\,l\,(t,Z_j) = e^{\sum b_i . Z_i}\,/\,e^{\sum b_j . Z_j} \qquad (4)$$

All the models where the risk function is separable in two terms only one of which depending on the time are called proportional risk models.

Moreover, in Cox model, the relation between instantaneous risks and environmental factors is log-linear:

$$\ln(l\ (t,Z)) = \ln(l_0\ (t)) + b_i.Z_i \tag{5}$$

Hence, Cox model is semi-parametric, log-linear and with proportional risks. Like in all regression models, interaction terms of environmental factors can be put in vector Z. Then, the vector of the b_i parameters can be estimated in maximising Cox's likehood:

$$L^* = \sum_{i=1}^{n}\left[b_i.Z_i - m_i \ln\left(\sum_{j\in R_i} e^{(b_j Z_j}\right)\right] \tag{6}$$

with m_i components failing at t_i.

The confidence on b estimator can be calculated by the usual tests like:

- the Rao-test or score test.
- the Wald test or test of the likehood maximum.
- the test of the likehood ratio: $c^2 = 2\left[L^*(b) - L^*(0)\right]$

All these test asymptotically follow c^2 distribution with p degrees of freedom, p is also the dimension of vector b.

Finally, an acceleration coefficient can be deduced from the b_i:

$$C_{P_{i,j}} = \frac{l\,(t,P_j)}{l\,(t,P_i)} = e^{b(Z_j - Z_i)} \tag{7}$$

It means that the risks to have a failure at a fixed date is $C_{P_{i,j}}$ times bigger when we go from environment Z_i to Z_j.

3.1 Concavity study

This paragraph shows the demonstration principle of the uniqueness Maximum of the likehood function. The calculations have been done until a two-factor model because of the length and complexity of the expressions to manipulate.

The likehood function concavity can be proved by deriving its expression until the second order and showing that this last expression keeps a constant sign on the real field. For a two-factor model, it is necessary to calculate the discriminant of the second degree terms of the Taylor's formula, so:

$$\begin{vmatrix} \dfrac{s^2 L}{s\ b_1^{\ 2}} & \dfrac{s^2 L}{s\ b_1 . s\ b_2} \\ \dfrac{s^2 L}{s\ b_1 . s\ b_2} & \dfrac{s^2 L}{s\ b_2^{\ 2}} \end{vmatrix} < 0 \tag{8}$$

Our investigation field is limitated to a two-factor model for the study of the Cox likehood maximisation.

3.2 Simulation

The simulation aim is to be able to verify the Cox model validity on a big number of tests. That's why a failure simulator has been developed for exponential, normal, log-normal, gamma and weibull laws. The value of the failures dates obtained are assigned to a Cox coefficient - cf. Example below - and we treat this new list of failures by Cox model. Then, the question is to know if we find again the previous acceleration parameters and to verify the relevance of the confidence obtained. The example of the exponential laws is presented below:

$$\Re(t,Z) = \exp\left[-\int_0^t l_0(t).dt.\exp\left(\sum_i b_i.Z_i\right)\right] \tag{9}$$

We choose a two-factor Cox model with the following code

Table 1.

CODAGE	Z_1	Z_2
Testing set 1	0	0
Testing set 2	1	0
Testing set 3	0	1

We choose b_1=ln(2) and b_2=ln(3), so the acceleration coefficients are respectively equal to 2 and 3. The table below has been obtained in generating three failure lists following an exponential law of coefficient l =0.05 the second and third columns have been balanced by the coefficient resulting from the code adopted (resp. 1/2 and 1/3 , cf. Equation 6):

Table 2.

Failure list	Testing set 1	Testing set 2	Testing set 3
Failure N°1	26.06	9.81	5.39
Failure N°2	27.47	1.62	2.37
Failure N°3	15.19	13.11	2.82
Failure N°4	8.37	6.22	10.92
Failure N°5	8.68	0.27	2.53
Failure N°6	4.22	6.63	0.31
Failure N°7	14.19	4.38	2.05
Failure N°8	27.43	30.48	11.46
Failure N°9	9.95	12.80	1.46
Failure N°10	16.45	1.77	13.87

The treatment of these datas by Cox model gives the following results:

b_1=0.604 compared with ln(2)=0.693
b_2=1.267 compared with ln(3)=1.099

So for the acceleration coefficient:

$C_{p_{0,1}}$ =1.83 compared with 2

$C_{p_{0,2}}$ =3.55 compared with 3

In order to test the validity of estimator b, we proceed to the test of the likehood ratio: $c^2 = 2\left[L^*(b) - L^*(0)\right] = 6.57$ so $a < 0.05$.

We can see ihat the theoretical values taken arbitrarily at the beginning have been found again with a satisfaying precision and confidence, considering the low size of the sample.

4 EXPERIMENTATION WITH REAL DATAS

4.1 Censored datas

One main interest of Cox model is the fact that it is able to consider the case of the censored datas. We generally find in the bibliography the ease of right simple censures because it corresponds to the stop of a test before the failure of all the components.

4.2 Jack's bench of testing wear

A testing bench for pneumatic jack is built. Pneumatic jack works in may different environements conditions, which are accelerated parameters. The wear is evaluated during all test by pression measure in the jack's chamber (Fig. 3). The datas below come from a pneumatic jack testing bench, (Fig. 1, Fig. 2).

Table 3.

Testing number	1	2	3	4
Pressure	7	3	7	7
Fluid temperature	47.5	47.5	25	47.5
Surrounding temperarure	35	35	35	0
Component number	6	5	5	5
Censure number	5	4	2	3
Censure date	4068	4004	4076	4040
Failure number	1	1	3	2
1^{rst} failure	2819	2927	1576	2797
2^{nd} failure	-	-	2044	3306
3^{rd} failure	-	-	3121	-

The code reference is the first testing set:

Table 4.

CODE	Test N°1	Test N°2	Test N°3	Test N°4
Pressure: Z_1	0	1	0	0
Fluid temperature: Z_2	0	0	1	0
Surrounding temperarure: Z_3	0	0	0	1

Environmental constraints: Z_1: fluid pressure, Z_2: fluid temperature and Z_3: surrounding temperature. Their influence is respectively noted b_1, b_2, b_3.

4.3 Result

So the result is: $c^2 = 3.04$ so a <0.4.

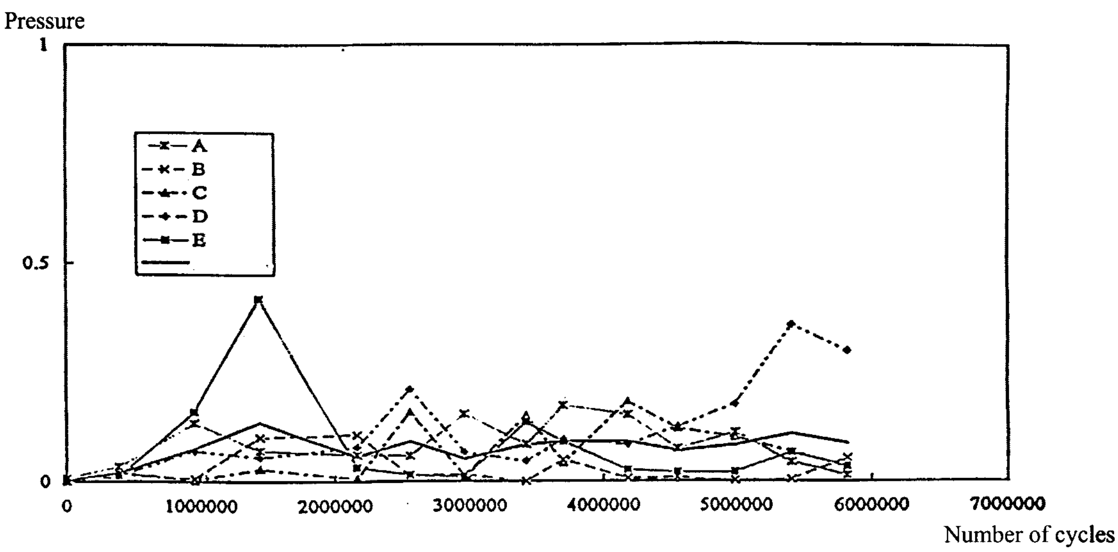

Figure.3. Testing bench for the measure of the leak of air

We can see that Cox model allows to obtain very effective results from small samples, even with strongly censored datas (the scale values are deliberately normalized, for purpose of industrial confidentiality). On the other hand, confidence has been reduced for this test.

Table 5.

Environmental constraint	1	2	3
Effect (b_i)	0.17	1.66	0.92
Acceleration ($C_{P\,0,i}$)	1.18	5.24	2.52

5 CONCLUSION

The first objective of this work was to build a data processing tool intended for manufacturers permitting to reduce the mechanical testing time. For this purpose, a new model, based on Cox model, has been defined in order to quantify the environmental influence on a testing set in the form of an acceleration coefficient. The way we have proceeded can be divided into four parts: acquiring the theoretical knowledge of Cox model, adapting and extending this model to mechanical reliability, developing a program of data analysis respecting the defined model, validating the proposed model using simulation (generator of failures).

This work is a part of bigger studies including the reduction of the testing time applied to pneumatic and hydraulic components, but will be validated by further tests.

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