TC

FATIGUE TEST PLAN TO OBTAIN S-N CURVES

João Mário Andrade Pinto'
CNEN/CDTN/IT1
P.O. Box 941
CEP 30123-970
Belo Horizonte, MG, Brazil
Tel.: 55-31-3499-3289
Fax: 55-31-3499-3390
e-mail: jmap@urano.cdtn.br

Enrico A. Colosimo
UFMG, Statistics Department
Belo Horizonte, MG, Brazil
e-mail: enrico@est.ufmg.br

Tanius Rodrigues Mansur
CNEN/CDTN/IT1
P.O. Box 941
CEP 30123-970
Belo Horizonte, MG, Brazil
Tel.: 55-31-3499-3381
Fax: 55-31-3499-3390
e-mail: tanius@urano.cdtn.br

Julio Ricardo Barreto Cruz
CNEN/CDTN/IT1
P.O. Box 941
CEP 30123-970
Belo Horizonte, MG, Brazil
Tel.: 55-31-3499-3343
Fax: 55-31-3499-3390
e-mail: jrbc@urano.cdtn.br

Ernani Sales Palma
PUC Minas, Dep. Eng. Mec.
Belo Horizonte, MG, Brazil
e-mail: palma@pucminas.br

Miguel Mattar Neto
CNEN/IPEN - Structural
Mechanics Division
São Paulo, SP, Brazil
e-mail: mmattar@net.ipen.br

ABSTRACT

S-N curves of structural materials are obtained through fatigue tests. These tests are often performed using five different stress levels, with fifteen test specimens for each stress level. This kind of test plan provides estimates that are less precise compared to other experimental plans, for example, the ones called optimum plan or compromise plan. The main reason for this drawback is the use of the same number of specimens for all stress levels. It has been observed that less precise results are obtained for lower stress levels because failure occurs less frequently. That is why more specimens should be used for lower stress levels as compared to higher stress levels. As long as the number of specimens to be tested at low stress levels is increased, the total number of failures will also increase, which allows one to develop a more precise data analysis.

The objective of this work is to present an alternative experimental plan to obtain S-N curves, which intends to provide accurate estimators. A practical application is done for planning a fatigue test, in a flex-rotating machine, to obtain the S-N curve of SAE 8620 steel.

INTRODUCTION

The S-N curve is a graph relating alternate stress levels to life expressed by the number of cycles for failure. These curves provide key information for the design of components or parts which operate under cyclic loading (Collins, 1981). Figure 1 shows a typical S-N curve. For an S-N curve obtained in a laboratory, the first step consists in planning the experiment. The plan for the experiment takes into account the following points:

(a) selection of stress levels;
(b) definition of the number of specimens to be tested at each stress level;
(c) choice of the test procedure to be used.

8565

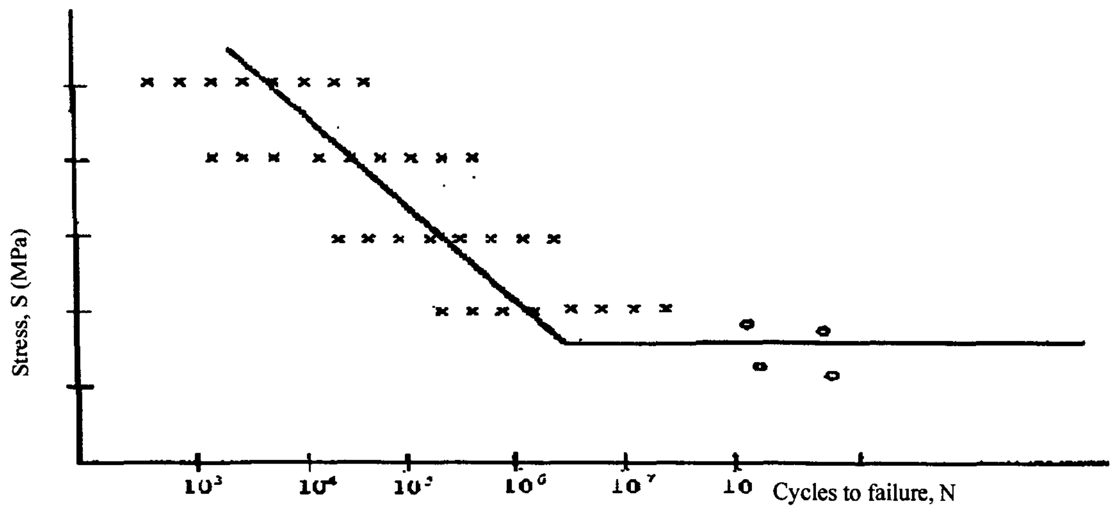

Figure 1. Tipical S-N curve

The first two points above will be addressed in this work, that is the selection of stress levels and definition of the number of specimens to be used in the test.

According to (Freitas & Colosimo, 1997) and to (Meeker & Hahn, 1985), there are three types of experimental plans:

Traditional plans

The traditional practice has been to establish three or four stress levels, equally spaced, and to assign the same number of specimens for each level.

Optimum plans

The optimum plans provide more precise estimators for the design conditions. These plans use two stress levels with a different number of specimens for each one. It is assumed that the higher stress level is pre-defined. Thus, it remains to choose the lower stress level. The use of only two stress levels derives from the difficulty of performing the necessary calculations for the plans involving more than two levels.

Compromise plans

Are those presented by (Meeker & Hahn, 1985). These plans are an intermediate proposal between the traditional and the optimum plans. They use three stress levels: high, medium and low. As in the case of the optimum plans, the high level is assumed to be chosen by practical considerations. The best low and medium levels are chosen in such way that the asymptotic variance of the 100P% percentile of interest of the lifetime distribution of the component under test, for design conditions, is minimized. There is the compromise that the number of specimens assigned, respectively, for the low, medium and high levels, always follows a 4:2:1 proportion. (Meeker & Hahn, 1985) present tables to make easy the choice of the plan.

The traditional plans, although very often used in practical cases (Collins, 1981), have the inconvenience of providing less precise estimators as compared to the ones provided by the optimum and compromise plans. The main reason for this drawback is the use of the same number of specimens for all stress levels. It has been observed that less precise results are obtained for lower stress levels because failure occurs less frequently. That is why more specimens should be used for lower stress levels as compared to higher stress levels. As long as the number of specimens to be tested at low stress levels is increased, the total number of failures will also increase, which allows one to develop a more precise data analysis.

The objective of this work is to present an alternative experimental plan to obtain S-N curves, which intends to provide accurate estimators. A practical application is done for planning a fatigue test, in a flex-rotating machine, to obtain the S-N curve of SAE 8620 steel.

COMPROMISE PLAN APPLICATION

Definition of stress levels

The material used is the SAE 8620 steel, with yield limit $\sigma_e = 370$ MPa and estimated fatigue endurance limit Se = 250 MPa.

The stress levels to be chosen should cover the whole S-N curve range. (Collins, 1981) suggests the use of four or five stress levels. Here, five stress levels will be used, three of them planned and two obtained through linear interpolation. Thus, the focus of this work, with respect to the stress levels definition, will be on those that are part of the planning.

According to (Freitas & Colosimo, 1997), the basic points of the compromise plan are:

(1) The use of three stress levels;
(2) Definition of which percentile (100P%) of the time-for-failure distribution is the most important for the study. For the case being analyzed here, 10% was chosen after several simulations;
(3) Choice of the highest stress level (Sa). In this case, the yield limit (370 MPa) was chosen;
(4) Choice of the lowest stress level (So). In this case, the fatigue endurance limit (250 MPa) was chosen;
(5) Specification of initial values for p_o (failure probability during the test with application of the lowest stress level) and for p_a (failure probability during the test with application of the highest stress level); in this work, after several simulations, the values were chosen as $p_o = 0.01$ and $p_a = 1$;
(6) Definition of the sample size; for the case studied here, in view of economical considerations, $n \leq 75$ was chosen; the number of specimens assigned for each stress level followed a 4:2:1 proportion, which is the proportion prescribed by the compromise plans;
(7) Specification of a time-for-failure distribution: Weibull or log-normal; here, a log-normal distribution was used;
(8) Specification of the stress-answer relation; in the present work, the inverse power law will be used (Freitas & Colosimo, 1997).

The values of low and medium stress levels are obtained from tables related to the corresponding log-normal distribution (Meeker & Hahn, 1985) and according to the following steps.

Step 1: x_a and x_o values

This values are transformations of the low and medium stress levels, respectively, and were already established by technical attributes. These transformations are based on the stress-answer relation. As the inverse power relation is being used, then

$$x_a = -\ln(S_a) = \ln 370 = -5.91$$
$$x_o = -\ln(S_o) = \ln 250 = -5.52$$

Step 2: Initial values for p_a and p_o

$p_a = 1$, which corresponds to a specimen failure probability of 100%, for a stress level of 370 MPa;

$p_o = 0.01$, which corresponds to a specimen failure probability of 1%, for a stress level of 250 MPa.

Step 3: Use of tables to find x_b (the transformed low stress level)

The x_b value is obtained by:

$$x_b = x_o + (x_a - x_o)\, x'_b$$

$$S_b = \exp(x_b)$$

The x'_b values are obtained from the so-called optimum plan, which provides the optimum x'_b, and from the adjusted plans corresponding to:

- optimum x'_b multiplied by 0.90;
- optimum x'_b multiplied by 0.80;
- optimum x'_b multiplied by 0.70;
- optimum x'_b multiplied by 0.60.

NUMBER OF SPECIMENS FOR EACH STRESS LEVEL

Due to economical considerations, the total number of specimens to be tested is a maximum of 75.

In view of that restriction, all plans defined above will be used to identify the one that will provide the number of specimens to be tested in the low stress level in order to comply with the previously mentioned restriction.

The values of x'_b and p_b are taken from the tables (Meeker & Hahn, 1985) and the remaining values are then determined.

Assuming that the expected number of failures is 3 for the stress S_b, the number of specimens that should be tested is $n_b = 3/p_b$.

Table 1 shows all the computations done.

Table 1. Results of the x_b and n_b computations

P	p_o	Adjusted Plan	x'_b	x_b	S_b (MPa)	p_b	$n_b = 3/p_b$
0.10	0.01	1	0,238	-5.61	273	0.188	16
0.10	0.01	0.90	0.214	-5.60	270	0.151	20
0.10	0.01	0.80	0.190	-5.59	268	0.120	25
0.10	0.01	0.70	0.167	-5.59	268	0.094	32
0.10	0.01	0.60	0.143	-5.58	265	0.072	42

Table 2. Plan outline

Stress	n	Failure probability	Expected number of failures
$S_o = 250$	—		0.01
$S_b = 268$	25		0.12
291	18		—
$S_m = 314$	12		0.898
342	9		—
$S_a = 370$	6		1.000
TOTAL	70		—

The chosen plan is the adjusted plan (optimum x'_b)*0.80, because the sample size, for this plan, is less than 75, as shown in Tab. 2.

Step 4: Use of tables to find xm

From the table corresponding to the log-normal distribution and to the adjusted plan (optimum x'_b)*0.80, the values $x'_m = 0.595$ and $p_m = 0.898$ are obtained. Thus:

$$x_m = x_o + (x_a - x_o)\, x'_m = -5.52 + (-5.97 + 5.52)\times 0.595 = -5.75$$

and

$$S_m = \exp(5.75) = 314 \text{ MPa}$$

CONCLUSIONS

Table 2 summarizes the result of the accomplished planning.

The intermediate values were determined by linear interpolation.

The use of a plan that is a fraction of the optimum plan brings about less accurate estimations. However, due to practical and economical restrictions for the particular case studied here, these less precise estimations are acceptable.

REFERENCES

COLLINS, J. A. *Failure of materials in mechanical design.* New York: J. Wiley, 1981.

FREITAS, M. A. COLOSIMO, E. A. *Confiabilidade: análise de tempo de falha e testes de vida acelerados.* Belo Horizonte: Fundação Christiano Ottoni, Escola de Engenharia da Universidade Federal de Minas Gerais, 1997. (Série Ferramentas da qualidade, 12).

MEEKER, W.Q., HAHN, G.J.. *How to plan an accelerated life test*, v. 10 – The ASQC Basic References in Quality Control: Statistical Techniques, Milwaukee, WI: ASQC – Quality Press, 1985.

TC

Separata

ipen

CENTRO DE ENGENHARIA NUCLEAR

Mecânica Estrutural

Fatigue test plan to obtain S-N curves

(New and Emerging Computational Methods: Applications to Fracture, Damage, and Reliability, Editors Brust, F.W., Nishioka, T. et al., ASME Publication PVP-Vol. 438, pp. 201-204, ISBN# 0791819493, The 2002 ASME Pressure Vessels and Piping Conference, realizada de 04 a 08 de Agosto de 2002, em Vancouver, British Columbia, Canadá)

Artigo Científico

P&D.CENM.CENM.019.00
ARTC.001.00

AUTOR	Rubrica	Data	VERIFICADOR	Rubrica	Data
João Mário Andrade Pinto		11.09.02			
Enrico A. Colosimo		11.09.02			
Tanius Rodrigues Mansur		11.09.02			
Julio Ricardo Barreto Cruz		11.09.02			
Ernani Sales Palma		11.09.02			
Miguel Mattar Neto		11.09.02			

APROVAÇÕES		Rubrica	Data
Chefe de Área	Miguel Mattar Neto		11.09.02
Lider	Miguel Mattar Neto		11.09.02
Gerente do Centro	Antonio Teixeira e Silva		17.09.02

ARQUIVO			