FIGURE-OF-MERIT FOR BARE AND COATED WIRES AND
FLAT RIBBON JUMPERS

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ABSTRACT

Wire and ribbon jumpers are often used in HMC's to bridge over other circuitry. A polymeric coating has been proposed for use as a stiffener under high acceleration loads. This work proposes a dimensionless Figure-of-Merit for jumpers and compares bare and coated jumpers via classical mathematical models and through a Finite Element Method (FEM) model. Real production geometry, end attachment conditions, and acceleration direction factors are explicitly included in the FEM model. The results do not justify adding the coating.

SUMMARY

Parylene coating of wire and ribbon jumpers on HMC's was proposed to be used in high acceleration environments. The justification was the improvement in stiffness to weight ratio. This study analyzes an idealized rectangular cross section jumper geometry using classical beam equations. A generalized deflection equation is proposed. From this, a dimensionless Figure-of-Merit is extracted. This Figure-of-Merit is the stiffness to weight ratio multiplied by a geometry factor which includes jumper size and shape, end attachment conditions, and acceleration direction. All comparisons are made using this dimensionless term.

The coating only provides a marginal improvement for some solid wire and ribbon conditions, but it slightly degrades other conditions and strongly degrades the performance of aluminum wire jumpers. A Finite Element Method (FEM) real geometry model dramatically shows the effect of the geometry factor. It also verifies that coated solid ribbons are inferior to bare ones. Thus, parylene coatings do not improve the strength to weight ratio of HMC jumpers. Other advantages must be identified to justify the added cost of coating HMC jumpers.

INTRODUCTION

Wire or flat ribbon jumpers are used in HMC circuitry to bridge over other electrical paths. These jumpers can be expected to deflect under high acceleration loads that are normal to air frames and missiles. A short circuit caused by deflection into contact with adjacent components on the circuit path under the jumper is the worst result. An electrical insulation coating on these jumpers can eliminate such unacceptable results.

A simple cantilever beam was used to infer the response of bare and parylene coated wire jumpers under high acceleration loads. The proposed Figure-of-Merit is the stiffness to weight ratio. Coated wire jumpers were concluded to be significantly better than uncoated jumpers.

This study addresses the question of whether or not coated jumpers are also improvements for other geometries and other acceleration directions. Closed form classical mechanics idealized solutions were supplemented with one Finite Element Method analysis of a geometry which more closely approximates the Bendix production design of HMC jumpers.

ACTIVITY

Wire or flat ribbon jumpers are used in Bendix HMC products to bridge over other circuitry and provide electrical connections. The simplest jumper geometry which can be analyzed in a classical

closed form mathematical solution is that of a rectangle with the base being the HMC substrate. The two vertical sides and top are wire or ribbon material in bare or coated condition.

The equations for the deflection collinear with the acceleration are shown in Table 1. Note that in each case a factor occurs which includes the specifics of the geometry, the end attachment conditions, and the direction of acceleration. These effects are collected in the bracketed term and named G in the proposed general form of the equations. The terms are grouped such that the Figure-of-Merit, K , is dimensionless. The K is just the strength to weight ratio modified by the geometry factor. The geometry factor incorporates into K the structural stiffness of the particular jumper configuration and attachment under the acceleration direction chosen. The reciprocal of K times the relative acceleration, a/g , and times a representative structural length, l , gives the maximum deflection at the top center of the jumper. The changes to stiffness and weight when the coating is added are additive.

Table 2 shows the calculated maximum deflections and Figure-of-Merit for the simple cantilever beam of Reference 1, the three directions of acceleration of a simple rectangular jumper, and for the two in plane accelerations of the FEM model. Case 1 is the cantilever beam of length $l = 0.889$ mm. Cases 2 through 4 are the simple rectangular jumper of height $l_1 = 0.889$ mm and width $l_2 = 1.27$ mm, one representative size at Bendix. The wire

Table 1. Deflection and Figure-of-Merit Equations in Closed Form

Case 1		$d = \left[\frac{1}{8} \right] \frac{\rho g A}{EI} \frac{a l}{g}$ $K = \left[\frac{8}{13} \right] \frac{EI}{\rho g A}$
Case 2		$d = \left[\frac{1}{8} l_1^3 + \frac{1}{6} l_1^2 l_2 \right] \frac{\rho g A}{EI} \frac{a}{g} l_1$ $K = \left[\frac{1}{8} l_1^3 + \frac{1}{6} l_1^2 l_2 \right]^{-1} \frac{EI}{\rho g A}$
Case 3		$d = \left[\frac{1}{8} l_1^3 + \frac{1}{6} l_1^2 l_2 + \frac{51}{384} l_2^3 \right] \frac{\rho g A}{EI} \frac{a}{g} l_1$ $K = \left[\frac{1}{8} l_1^3 + \frac{1}{6} l_1^2 l_2 + \frac{51}{384} l_2^3 \right]^{-1} \frac{EI}{\rho g A}$
Case 4		$d = \left[\frac{51}{384} l_2^3 \right] \frac{\rho g A}{EI} \frac{a}{g} l_2$ $K = \left[\frac{51}{384} l_2^3 \right]^{-1} \frac{EI}{\rho g A}$

General Case-General Equations

$$d = G \frac{\rho g A}{EI} \frac{a}{g} l$$

$$K = G^{-1} \frac{EI}{\rho g A}$$

E = Young's Modulus
I = Cross Sectional Moment of Inertia
 ρ = Mass Density
g = Acceleration of Gravity
d = Maximum Deflection

G = Geometry Factor
A = Cross Sectional Area
 l_1, l_2, l = Length Dimensions
a = Acceleration
K = Dimensionless Figure-of-Merit

Table 2. Deflection and Figure-of-Merit for 20,000 g's Acceleration

Pictorial Description	Jumper Type	Jumper Material	Deflection, d (m)		Figure-of-Merit	
			Bare	Coated	Bare	Coated
Wire	Au	99.3	92.6	0.179	0.192
Wire	Al	17.1	27.5	1.042	0.647
Wire	Au	280.0	262.0	0.0676	0.681
Wire	Al	48.1	77.2	0.370	0.231
Ribbon	Au	52.6	52.0	0.339	0.343
Wire	Au	332.	301.	0.0553	0.0592
Wire	Al	55.3	88.6	0.322	0.201
Ribbon	Au	9.67	9.98	1.842	1.820
Wire	Au	29.3	27.4	0.607	0.651
Wire	Al	5.02	6.06	3.542	2.208
Ribbon	Au	5.49	5.43	3.240	3.277
Ribbon	Au	7.92	8.42	4.493	4.221
Ribbon	Au	0.565	0.579	31.46	30.70

* SLA Simple Cantilever Beam Model.

** Rectangular Jumper Model For Closed Form Mathematical Solutions.

*** FEM Model Functional Geometry: K was Back Calculated = $\frac{al}{gd}$

diameter used was 0.025 mm and the ribbon was 0.127 mm wide by 0.0508 mm thick. The coating for all cases was 0.001 mm thick. The acceleration was 20,000 g's. Cases 5 and 6 are for the FEM model of gold ribbon geometrically close in size and shape to an actual Bendix production jumper. An effective K was back calculated from $K = a/l/g_0$ for the FEM model cases.

The Figure-of-Merit for all aluminum jumpers is lower when they are coated rather than bare. The K for the gold ribbon FEM model was also lower when it was coated. In all other cases, only marginal differences exist between bare and coated jumpers. Since jumper merit dictates higher stiffness and lower weight for improvement, higher K values also correspond to improved jumpers. Thus, it is seen that whether or not jumper geometry, end support conditions, and direction of acceleration are included in the Figure-of-Merit, or when looking at deflections, the parylene coating cannot be justified. It does not significantly improve (always less than 10 percent improvement) any condition investigated. Some other reasons, such as electrical insulation, would have to be the justification for the added cost.

Figures 1 through 4 show deflection pictures for the FEM model. Figures 1 and 2 are for acceleration parallel to the jumper base when bare and when coated. The dotted lines indicate the undeflected jumper geometry. Comparison of bare and coated pictures shows the very small deflection difference (the deflec-

TYPE
PLOTDISP 1.

SET 1
LOAD VALUE 1.00
BR-SZ SCALE FACTOR -
ZMIN ZMAX
-1.0040-06 .000000
RMIN RMAX
-1.001004 .001004
TYPE

Figure 1. FEM Model of Bare Gold Ribbon Accelerated Parallel to its Base (Dotted Lines Are the Undeflected Position)

Figure 2. FEM Model of Parylene Coated Gold Ribbon Accelerated Parallel to its Base (Dotted Lines Are the Undeformed Position)

PLATE

Figure 3. FEM Model of Bare Ribbon Accelerated Perpendicular to its Base (Dotted Lines Are the Undeflected Position)

ZMIN	ZMAX
- .000136	.000143
RMIN	RMAX
- .000074	.000001

TYPE

SET 1
LOAD VALUE 1.00
R-SZ SCALE FACTOR .

CONTRIBSON
CONTRIBSON
07/23/79 15.66.26.
07/23/79 15.48.57.
15.43.40. 07/23/79
1.00 1.00

1 4 3

1.0000

12

tions are magnified by 12 in Figures 1 through 4) which corresponds to the marginally lower Figure-of-Merit for the coated jumper in Table 2. A similar very small difference is noted between Figures 3 and 4 for bare and coated jumpers under acceleration perpendicular to the base. Note that this arched geometry deflects much less and has a much higher Figure-of-Merit than the idealized rectangular jumpers. This dramatically shows the geometry effect.

CONCLUSIONS

The following conclusions are based on the data previously presented.

- o A geometry factor is needed in the Figure-of-Merit in order to include the specific details of size and shape, end attachment conditions, and direction of acceleration. The choice made here results in a dimensionless Figure-of-Merit proportional to the stiffness to weight ratio.
- o Parylene coated aluminum wire jumpers are definitely inferior to bare ones. The coating causes a larger deflection and a lower Figure-of-Merit.
- o Parylene coating on solid wire or ribbon jumpers has only a small effect. In some cases the coated jumpers are slightly inferior, but in others they are slightly superior.
- o The added time and cost of the parylene coating process can't be justified from higher Figure-of-Merit or stiffness to weight ratio. Other considerations, such as electrical insulation, must provide the justification.