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METAL VAPOR EXCIMER LASER

**Quarterly Progress Report
for period August 1, 1978 - October 31, 1978**

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I. INTRODUCTION AND SUMMARY

Progress in the metal vapor excimer program was slowed in this quarter as a result of a fire which occurred in the apparatus. As this period closed, the fire related damage had largely been repaired; in spite of the setback there will be sufficient time to generate data for the mid-December workshop meeting. Initial design considerations for the foil and foil support of a high temperature, transverse e-beam discharge device have been generated. In addition, foil material testing has been performed.

II. EXPERIMENTS

During September we were involved in conducting heating tests of the full system which includes the metal vapor supply, heated fill lines, and discharge tube oven. Unfortunately, on the evening of September 13, a fire started in the experiment which damaged the heating circuitry, the experimental table and a few pieces of electrical equipment. No major pieces of equipment, e.g., e-beam, magnet power supply, control circuitry, oscilloscopes, or metal vapor supply oven, were damaged. The origin of the fire was not conclusively determined because it destroyed nearly all the control, sensing and power lines immediate to the experimental area. It is more probable that the fire resulted from an equipment failure since the experiment had been running with no noticeable problem for at least 30 hours prior to the fire. In addition, the assembly had run for extensive periods, at least 8 hours each, prior to this particular run.

Rebuilding the experiment has taken ~ 7 weeks and has dominated the total efforts of the metal vapor program this quarter.

A. FOIL MATERIAL TESTS

Some initial foil corrosion resistance tests of titanium and beryllium were made. Samples of pure titanium and beryllium

foil material (1 and 2 mil) were heated in the presence of cadmium vapor at a pressure of 35 torr and a temperature of 550°C for 96 hours using the apparatus described in previous reports. After removal from the test vials, we found that the titanium surfaces had lost their original sheen and had taken on a dull gray appearance. One of the titanium samples became slightly brittle; certainly further investigation is needed here to establish whether embrittlement is a problem. The beryllium sample remained unaffected except for a slight discoloration, i.e., a golden film covered the once matte gray finish. No sign of embrittlement appeared.

III. FOIL AND FOIL SUPPORT DESIGN

In a transverse pumped electric beam pumped discharge device, a large area foil capable of operating at high temperature and pressure will be necessary. We have carried out an initial design study to determine the most suitable foil material and support structure design to accommodate such a system. Clearly, a large number of elements come into play in determining the best overall approach; for example, stopping power of the foil, strength at temperature, corrosion resistance and availability of materials.

As a starting point for the design, we assumed that the system would operate at 6 atm at 600°C with a neon, mercury and cadmium mixture in the ratios of 50:10:1. A one dimensional AERL developed, electron beam energy deposition code was then used to evaluate the energy deposited in this mixture for various foils, materials and thicknesses at several incident energies. This calculation was coupled to a further calculation which related foil and foil support strengths to extract an effective energy deposition which accounted for the geometric transmission factor of the support structure and the energy lost in the foil itself.

This study compares the efficiency of various foil and foil support materials for a particular laser configuration; maximizing

the proportion of energy deposited in the lasing medium by a 375 keV e-beam is the criterion for selecting a given foil and foil support material.

The assumed laser configuration has a 5 cm by 5 cm cavity cross section and contains a 5:1 Ne-Hg mixture at a temperature of 600°C (1100°F). Densities of both 1 and 2 amagat were considered. The e-beam is operated in a single-pulse mode and the energy deposited in the foil is not significant, therefore thermal conductivity and capacity of the foil were not factors to be considered.

A. FOIL SUPPORT

The foil support is the conventional barred type where the bars, of width b, depth h and spacing x, span the short dimension of the e-beam window. (See Figure 1)

Considering the bars as fixed-end beams of length ℓ the maximum bending moment (Page 5-32 Ref. 1) is:

$$\frac{w\ell^2}{12}$$

where w is the uniformly distributed load, in this case $P(x + b)$ #/in, where P is the cavity pressure, then

$$M = \frac{P(x + b)\ell^2}{12}$$

and the stress $\sigma = \frac{M}{Z}$ where Z (the section modulus) = $\frac{bh^2}{6}$

From this the stress can be written: $\sigma = \frac{6P\ell^2}{12h^2} \frac{x + b}{b}$

The obscuration caused by the support bars is: $\theta = \frac{b}{x + b}$

H7901

Figure 1. Schematic of Foil and Foil Support

Substituting in the equation above: $\sigma = \frac{6P\ell^2}{12h^2\theta}$

In the present case $\ell = 1.97"$ (5 cm) and the stress equation becomes:

$$\sigma = \frac{1.94P}{h^2\theta}$$

or

$$h = \frac{\sqrt{1.94P}}{\theta\sigma}$$

B. FOIL SUPPORT MATERIALS CONSIDERED

1. Rene'41

This is one of the nickel-based superalloys and is expensive both to purchase and machine. For this reason a target lifetime of 500 hours at 1100°F was selected. Stress data (Page 519 Ref. 2) gives 100 hours (to rupture) at 120000 psi and 1000 hours at 105000 psi. For this study 110000 psi was selected as the design stress.

2. Type 316 Stainless Steel

This material has the best hot strength of the Austenitic stainless steels, is readily machined and is much cheaper than Rene'41. In view of this a shorter lifetime of 200 hours was considered acceptable. Rupture data for this lifetime is not given but available data (Page 482 Ref. 2) indicates that allowable stresses are 50% higher than Type 304 which can tolerate (Page 503 Ref. 2) 30000 psi under these conditions. On this basis an allowable stress of 45000 psi was assumed.

Cavity pressures of 45 psi and 90 psi (corresponding to densities of 1 and 2 amagat) were considered. Using these, and the design stresses selected, in the previously derived equation, we calculated the relationship of bar depth to obscuration fraction. For convenience the results are plotted in Figure 2 as a function of transparency rather than obscuration.

C. STRESSES IN FOIL

Foil stresses were calculated by a method, frequently used in the past, which gives reliable results. This is done by adaptation of catenary formulae (Page 2-56 et seq Ref. 1) as follows.

A foil strip, of unit width, is assumed to have a weight per unit length equivalent to the cavity pressure. The tensile load in the catenary is a function of the depth of the curve ($\frac{s}{x}$) through the auxilliary variable z , given in Table 2 of the reference. Substituting the relationship given for the parameter of the catenary and factoring in the cross-sectional area of the foil strip gives an equation for stress:

$$\sigma = \frac{P}{t} \frac{\frac{x}{2}}{x} \frac{s}{z} \frac{\cosh z}{z}$$

where P is the cavity pressure, x is the support bar spacing and t is the thickness of the foil. The relationship, $\frac{s}{x}$, is now a measure of foil elongation and is included to allow for the resulting reduction of cross section.

H7891

Figure 2. Foil Support Bar Depth vs Transparency

Initially, the foil is assumed to be fitted without slack, $s/x = 1 + \frac{\sigma}{E}$, where E is Young's Modulus at the temperature of interest. Initial stresses are high but the onset of creep causes an increase in s/x and a decline in stress, rapid at first and then continuing at a reducing rate throughout the foil lifetime. To determine the bar spacing for a particular foil it is necessary therefore to select both a design stress and the elongation at which the stress is to be calculated.

D. FOIL MATERIAL DATA

Data for suitable materials, available in foil form, has been researched and a summary follows. The selection of design stress for each is based on a target lifetime of at least 50 hours under operating conditions. Determination of stress criteria is complicated by the fact that published data is not based on tests of foil and the results from tests on sheet and bar may not be directly applicable.

1. Titanium

Data taken from Page 537 (Ref. 2) indicates that rupture occurs at $\approx 7\%$ elongation at all temperatures up to 1000°F (the limit of the data). It is estimated that a foil under 6000 psi stress at 5% elongation would give the desired lifetime.

2. Alloy Ti-3Al-2.5 V

There is no published data available on this alloy but verbal communication from a vendor indicates that its properties are close to those of TI-6Al-4 V. Creep strength of the latter,

from curves on Page 528 Ref. 2, appears to be about 3 times as high as that of pure Ti. For this study a conservative design stress of 12000 psi at 5% elongation was assumed.

3. Stainless Steel Type 304

From the relevant curve (Page 503 Ref. 2) a stress of 30000 psi would give a lifetime of 100 hours; the elongation resulting (extrapolating from the curve) would be about 2-3%. For study purposes a stress of 30000 psi at an elongation of 1% was assumed.

4. Inconel 718

Foil is also available in two other alloys (600 and 625) but 718 presents the best combination of hot strength and transparency to electrons. Creep data is only available (Ref.3) for hot rolled and aged bar but the data for cold-rolled and aged sheet shows a higher yield stress at elevated temperatures. From the data for bar stock a lifetime of 100 hours can be expected at 130000 psi and 1100°F, the elongation being 2% at that time. For study purposes a design stress of 120000 psi at 1% elongation was assumed. With the above data in the foil stress equation, previously derived maximum bar spacings were calculated. The results are presented in Table I for several thicknesses and two cavity pressures.

E. BAR WIDTH

The minimum bar width is not easily defined analytically. If the ratio h/b is very large instability problems could arise

TABLE I
MAXIMUM BAR SPACING AS A FUNCTION
OF FOIL AND DENSITY

<u>Medium Density</u>	<u>Foil Material</u>	<u>Foil Thickness (inch)</u>	<u>Bar Spacing (inch)</u>
2 Amagat (P = 90 psi)	Ti	0.001	0.060
	"	0.002	0.120
	Ti-3Al-2.5 V	0.001	0.120
	"	0.002	0.240
	304 St Stl	0.001	0.157
	"	0.00005	0.078
	Inconel 718	0.001	0.627
1 Amagat (P = 45 psi)	Ti	0.001	0.120
	"	0.002	0.240
	Ti-3Al-2.5 V	0.001	0.240
	"	0.002	0.480
	304 St Stl	0.001	0.313
	"	0.0005	0.157
	Inconel 718	0.001	1.254

although these are not usually restrictive in such a short beam. Practical machining considerations indicate a limit of about 0.02" as bars thinner than this are difficult to machine due to lateral bending under pressure of the milling cutter. For the study an arbitrary ratio of $\frac{h}{b} = 3$ was selected as a maximum value. Curves plotted on Figure 3 show transparency vs bar width for the bar spacing dimensions shown in Table I. Cross plotted are curves of transparency vs one third of the bar depth given in Figure 2. The appropriate intersections are taken as the optimum foil support transparency for each combination of material and pressure.

The energy deposited in the lasing medium is shown in Figure 4. The program calculates the energy absorbed in the foil, of various materials and thicknesses, as well as the energy absorbed in 5 cm of the lasing medium at the two densities noted.

To arrive at the true amount of energy deposited it is necessary to multiply the data in Figure 4 by the optimum transparencies derived from Figure 3, giving the data presented graphically in Figure 5.

F. RESULTS

1. Foil Support Material

The results of this study (See Figure 5) show that a foil support made of Rene' 41 allows a slightly higher transparency

Figure 3. Transparency vs Bar Width for Bar Spacings Given in Table I

AVERAGE ELECTRON ENERGY DEPOSITED IN CAVITY
 375 KeV E-BEAM - CAVITY WIDTH=5 cm
 LASING MEDIUM - 5:1 Ne:Hg

H7889

Figure 4. E-Beam Energy Deposited in 5 cm of Metal Vapor/
 Buffer Gas Mixture at 1 and 2 Amagat for Various
 Foils. Energy = 375 keV

% ENERGY DEPOSITED IN LASER CAVITY
CAVITY WIDTH = 5cm - 375 KeV E-BEAM
LASING MEDIUM - 5:1 Ne:Hg
DENSITY - 2 AMAGAT - TEMP - 500°C

H7890

Figure 5. Percentage of E-Beam Energy Deposited in 5 cm of Metal Vapor/Buffer Gas Mixture as a Function of Foil and Foil Support Materials. Energy = 375 keV

than one of 316 stainless steel. However, it is questionable whether the greater working difficulties are justified.

2. Foil Material

The titanium alloy (Ti-3Al-2.5 V) appears to be the best choice for the conditions considered and may show to greater advantage when more definitive properties are available. Inconel 718 is twice as opaque to electrons as titanium but its superior hot strength counteracts this to a great extent. Stainless steel is less efficient than either of the above but it may be preferred on account of the lower cost.

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1. Standard Handbook for Mechanical Engineers - 7th Edition, McGraw Hill Book Co.
2. Metals Handbook Vol. 1 - 8th Edition, American Society for Metals.
3. "Inconel 718" - Data booklet (3rd Edition) published by Huntington Alloys Inc., Huntington, W. Va.

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