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High Resolution Video Monitoring of Coating Thickness During Plasma Spraying

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ABSTRACT

A new approach for monitoring the thickness of plasma sprayed coatings during application is described. The method employs a high resolution video camera and width analyzer to accurately measure the dimensions of samples having simple geometries. This approach is best suited for cylindrical or flat substrates but it may also work for selected locations on more complex geometries. Measurement accuracy is a function of specimen dimensions and extent of magnification. For example, the thickness of a coating applied to 0.5 in. (1.27 cm) cylinders can be read to about 0.3 mil (0.008 cm). Thus, tolerances of ±0.5 mil (0.13 mm) on final coating thickness can be achieved. Additionally, the plot of cumulative coating thickness versus the number of passes has proven to be a useful diagnostic tool. While the ideal plot is linear, strong deviations from linearity--indicating the need for corrective action--may be observed.

PLASMA SPRAYED COATINGS are generally built up layer-by-layer until a target thickness plus or minus a specified tolerance is reached. However, even when spray parameters have been well established, variations in the spray process generally result in some variation in the number of passes required to achieve the target thickness. In other cases, where spray parameters are not well established, there is even more uncertainty in the expected deposition rate. In either case the process generally has to be interrupted periodically to manually measure coating thickness. These interruptions are undesirable. The time required to manually measure thickness adversely affects productivity; also, the layers sprayed after cooling for inspection may have an altered residual stress state, and a micrometer can mar some surfaces. On the other hand, deposition rates higher than anticipated may lead to overshooting the target thickness and necessitate specimen rejection or rework. Therefore, methods for automating coating thickness measurements are needed. Initial approaches have involved the measurement of reflected light using fiber optic bundles (Refs. 1 and 2) and the measurement of eddy currents (Refs. 2 and 3). The disadvantage of these approaches is that they require contact or near-contact, which necessitates moving the sensing device in proximity to the specimen. Also, fiber optic or eddy current sensors must be calibrated to a specific coating system since their response will vary with changes in the reflectivity or porosity of the coating. In the majority of production applications, where irregularly shaped objects must be repeatedly sprayed, such proximity sensors are needed. However, in many cases the objects being coated have simple geometries such as cylinders or flats. This is often true in production and it is normally true in the research and development of new coatings and spray processes. Thus, the purpose of this paper is to describe a new approach developed for monitoring the thickness of plasma sprayed coatings during application. The approach employs a high resolution video monitor and width analyzer for noncontact thickness measurement. The suitability of this technique for reproducibly processing test specimens will be discussed and the utility of this technique as a plasma torch diagnostic tool will be noted.

APPROACH TO HIGH RESOLUTION VIDEO MONITORING

The apparatus used for video thickness monitoring is built around a commercially available high resolution video camera, camera control unit, and width analyzer.* Close up magnification at a sample-to-camera distance of about 7 ft (2 m) is achieved through the use of a 700 mm mirror telephoto lens with a 10.5 in. (27 cm)

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*Hamamatsu Vidicon Camera and Control Model C1000; Width Analyzer Model C1170. Hamamatsu Corporation, Waltham, MA 02154.

extension tube between the lens and the video camera. (It may be noted that a more readily available 500 mm telephoto lens could have been used equally well for this application.) This apparatus is illustrated schematically in Fig. 1. Several other essential features of the apparatus are shown in the figure. First, the specimen is viewed silhouetted against an intense 1000 W quartz lamp. A diffusing lens placed between the lamp and the specimen assures a more uniform bright spot. This lamp with its associated diffusing lens appears brighter--at the substrate--than the plasma flame. Therefore it is not necessary to use a shutter to protect the camera from the radiation of the flame, although a filter such as a number 6 welders shade must be placed in front (or behind) the telephoto lens. Another advantage derived from viewing the specimen in silhouette is that this approach appears to lessen the need for a high quality lens. The arrow drawn above the substrate in Fig. 1 indicates that a cylindrical substrate is usually rotated during the coating operation. The video system responds fast enough to track any wobbling of the specimen. The thickness monitor may also be used for other substrate geometries. For example, the rotating specimen in Fig. 1 could be replaced by a flat substrate viewed on edge or an arbitrarily shaped substrate viewed at any convenient tangency point. In either case the substrate must be viewed across its entire thickness or it must be fixtured very rigidly. Finally, a dust cover should be draped across the camera and lens if the video system is in the same room as the plasma torch.

The monitor drawn in Fig. 1 displays on its screen a negative, high contrast, close-up image of the specimen. The bar in the center of the image is placed on the screen by the width analyzer. This bar detects the number of lines of the white specimen contrasted against the black background. A total of 1024 lines are available. The available resolution is a function of the specimen dimensions and the extent of magnification. In a typical example, a 0.5 in. (1.27 cm) diameter specimen is magnified to fill up about 75 percent of the screen. This means that the width analyzer will read approximately 768 lines (i.e., 75 percent of 1024) and implies that one line represents about 0.65 mil (0.0017 cm) on the diameter or 0.33 mil (0.0008 cm) on the radius. Since fractional line widths can be estimated, theoretical resolution may even be somewhat better. Therefore coating thickness on a 0.5 in. cylindrical specimen can be read to a theoretical resolution of less than one third of a mil. A typical coating thickness of 10 mil (0.025 cm) should increase the reading by 30 lines. However, in practice it is necessary to increase the value to about 33 lines to account for thermal expansion due to substrate heating. (A 0.5 in. diameter superalloy specimen will expand about 1 mil for every 150 °C increase in temperature.) Changes in the positioning of the camera and changes in the tuning of the camera and width analyzer will, from time to time, yield slight changes in the values used above for illustration. Therefore calibration with premeasured samples is advisable.

The following step by step procedure illustrates how the video monitoring system may be used for routine sample preparation:

(1) Align the camera, specimen, and lamp--insure that the lamp is equally bright on each side of the specimen.

(2) Tune the width analyzer and camera.

(3) Check calibration with "before" and "after" samples to determine expected increase in lines.

(4) Measure the substrate diameter with a micrometer.

(5) Light the plasma torch and introduce the powder.

(6) Instruct the robot to move the gun to a rest position near the specimen.

(7) Read the width analyzer; if the reading flips between two values estimate the reading to the nearest one-fourth line.

(8) Spray the first pass.

(9) Return to the rest position and pause briefly to cool the part.

(10) Read the width analyzer.

(11) Spray the next pass--repeating until the target thickness is reached.

(12) Shut down and confirm thickness with the micrometer.

EXPERIMENTAL EXAMPLES

Several examples of outputs obtained from the video system during plasma spraying are presented in the following figures in order to illustrate the advantages and limitations of this technique. The first plot, Fig. 2, represents optimum plasma torch and thickness monitor operation. It is a plot of the increase in TV lines (proportional to coating thickness) versus number of plasma spray passes. A scale for coating thickness is also given. This thickness scale is simplified by allowing all of the thermal expansion to occur initially. In this and the following examples zirconia-yttria ceramic coatings were applied to 0.5 in. (1.27 cm) cylindrical substrates. The final slope of the plot is linear to within the readability of the width analyzer. The initial curvature is attributed to thermal expansion of the specimen as its temperature rises to a steady state value. The target thickness in this case was 10.0 mil (0.025 cm) or 33 lines. Spraying was stopped at 32-3/4 lines (9.9 mil), and the thickness increase measured with a micrometer was 10.1 mil. Such ideal results required very careful alignment, very uniform illumination, calibration, and a well behaved spray process. Figure 3 shows a typical plot where small but normally acceptable deviations from ideality are observed. In this case the final slope departed from linearity. Spraying was stopped at 33-1/2 lines (10.2 mil). And, the final measured thickness of 10.6 mil was considered to be within tolerance.

Figure 4 shows the plot of the change in lines and the coating thickness versus number of passes for a case where the spray process was not under control. A prior calibration specimen sprayed under nominally the same spray conditions had been sprayed at a deposition efficiency of about 0.6 mils per pass. However, in Fig. 4 the deposition efficiency was markedly lower, especially after the first few passes, and the slope of the curve appeared to periodically drop to zero. The problem was traced to clogging of the zirconia-yttria powder at the internal powder port. The periodicity in the slope of lines versus passes appears to be due to the clog partially opening then partially closing again. (This problem was alleviated by narrowing the powder port diameter by placing hollow inserts into the port. This presumably increased injection velocity and altered the temperature at the port exit.) Finally, Fig. 5 gives an example of a plot for a case where the specimen is silhouetted against a lamp with insufficient illumination. The result was a rather noisy signal where the readability degraded to about ±1 mil.

CONCLUDING REMARKS

A high resolution video thickness gauge has been developed for monitoring the thickness of plasma sprayed coatings during deposition. It was shown that a high resolution video camera and width analyzer can be used to very accurately measure thickness, especially for coatings on cylindrical and flat substrates. It was also shown that the plot of thickness versus number of passes serves as a very good indicator of plasma torch performance. That is, large deviations from linearity in the plot of cumulative thickness the number of passes help to flag the need for corrective action.

Further extensions of the techniques described above for video thickness gauging to other types of coating processes or to any of numerous other measurement needs may be envisioned.

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3. T.E. Strangman, J. Neuman, and A. Liu: CR-179648 (Garrett 21-6355), National Aeronautics and Space Administration, Washington, D.C., 1987.

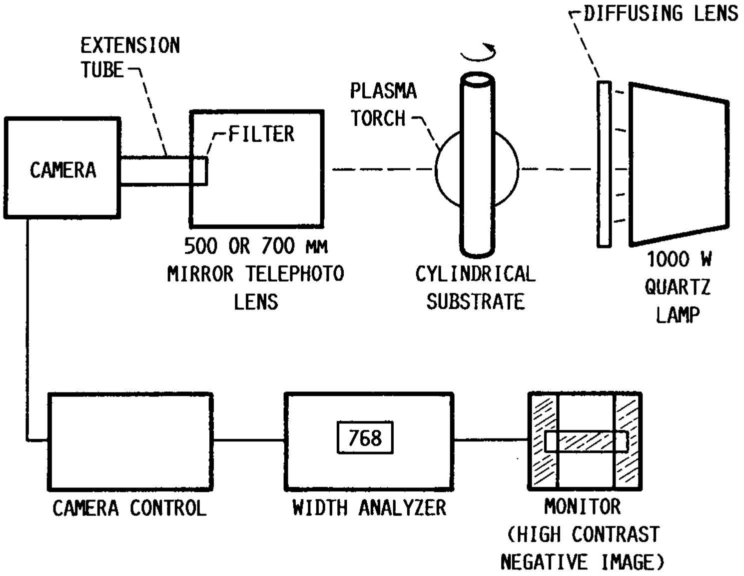

FIGURE 1. - SCHEMATIC OF VIDEO THICKNESS MONITORING SETUP.

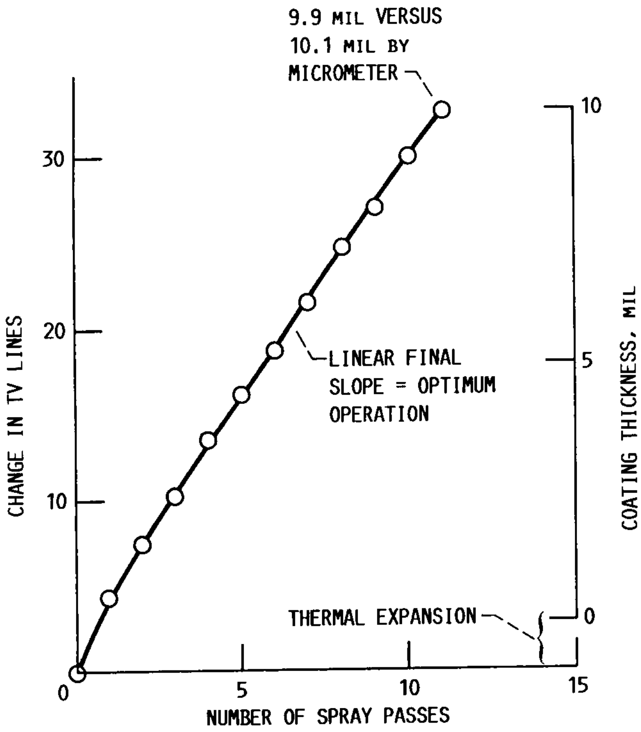

FIGURE 2. - PLOT OF CHANGE IN TV LINES AND AND COATING THICKNESS VERSUS NUMBER OF PASSES FOR OPTIMUM PLASMA TORCH AND MONITORING SYSTEM OPERATING CONDITIONS.

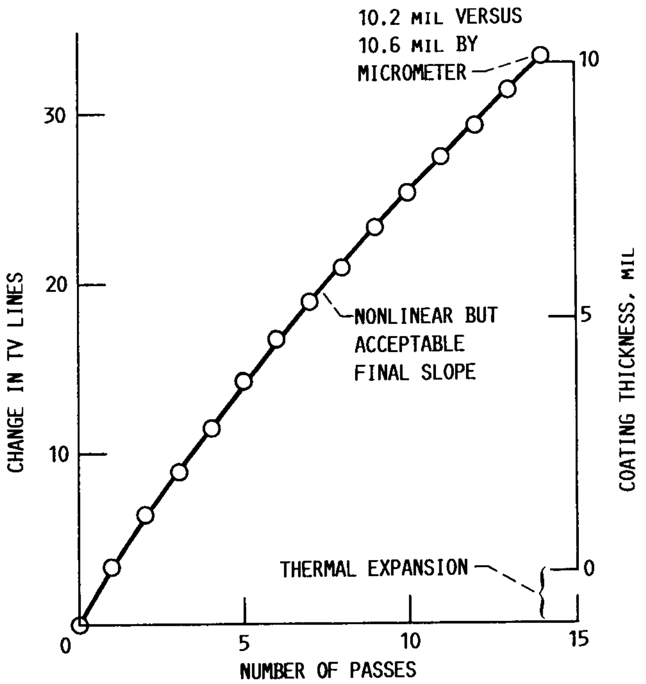

FIGURE 3. - PLOT OF CHANGE IN TV LINES AND COATING THICKNESS VERSUS PASSES FOR NON-OPTIMUM BUT ACCEPTABLE OPERATING CONDITIONS.

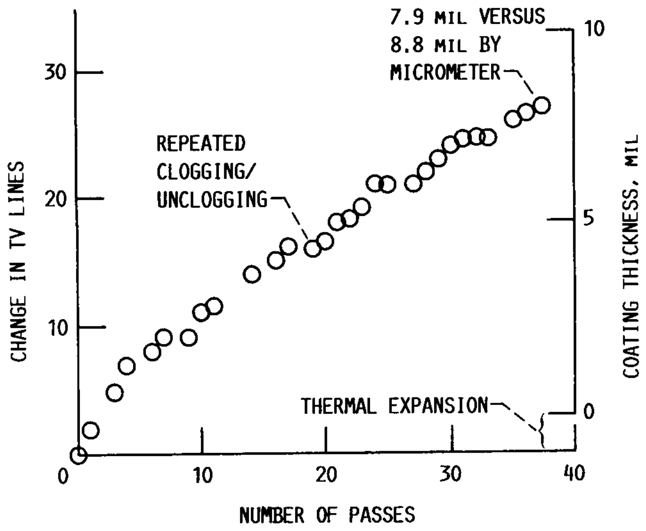

FIGURE 4. - PLOY OF CHANGE IN TV LINES AND COATING THICKNESS VERSUS PASSES FOR A SPRAY PROCESS THAT WAS NOT UNDER CONTROL.

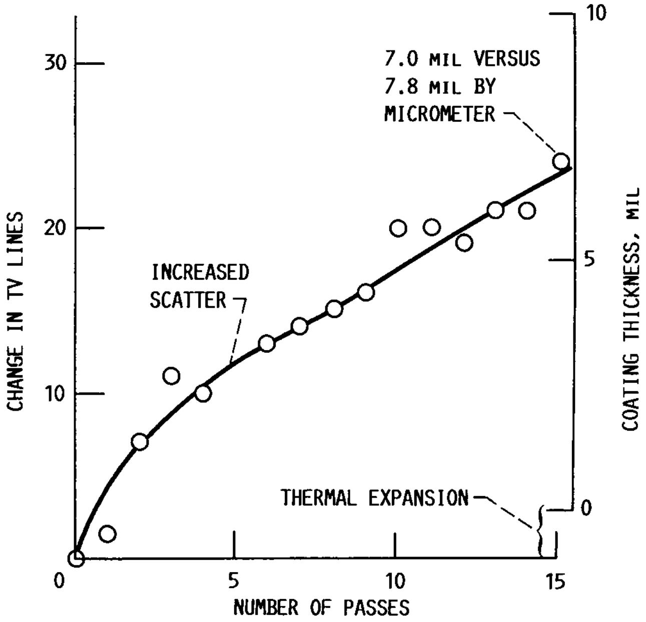

FIGURE 5. - PLOT OF CHANGE IN TV LINES VERSUS PASSES FOR THE CASE OF INSUFFICIENT ILLUMINATION.

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