GENERAL DISCUSSION

MR. C. D. MORIARTY.[1]—I was very interested in the test procedure on large forgings outlined by Mr. Kelman. Our procedure at Schenectady is to test at the time of the first operation on the incoming forging. The test is made while the forging is rotating in the first lathe operation. In this way every cubic inch of the forging is examined and questionable areas are marked, within a period of 2 hr. When necessary, oscillograms are taken with a Land Polaroid Camera and engineering decisions thereby expedited. These decisions pertain to the type and extent of correlation information needed to pass on the acceptance of such questioned forgings.

We have occasion to test thin material with the reflection method. For this type of work, we have designed a concentric type of holder containing two crystals, the receiver crystal in the form of a ring around the central transmitter crystal. By this method, we have sorted out laminated $\frac{1}{8}$-in. thick material.

In testing the turbo-generator rotors, we use one megacycle. With respect to this matter of frequency, Mr. Kelman showed a hammer method as his original sonic method. We went through the same experience, but in 1937 we hooked a sound receiver and an oscilloscope to this hammer set-up, and took oscillograms of the sound reflections. The records show thermal cracks detected by this low-frequency audible compressional wave. Of course, it was just a one pulse method requiring precision timing. In 1943, after obtaining a Firestone Reflectoscope, we got much better results. During the war, we tried frequencies from one to ten megacycles on gas turbine rotors. While we have other frequencies available, we still find one megacycle entirely adequate on turbo-generator rotors. I should like to comment on Mr. Kelman's remarks on the wearing of crystals. On our large rotor forgings, we use spring-mounted crystals. I have estimated that we have tested about three acres of turbo-generator rotor steel surface moving at the rate of 6 in. per sec. with no visible wear of the quartz crystals. Wear depends upon the back pressure, or the pressure of your hand in the case or rigid mounted crystals.

MR. A. W. F. GREEN.[2]—In 1945, in a very early engine of the I40 type that we had built, we experienced a broken turbine wheel. The turbine wheel was a conventional forging of 16-25-6 alloy, and had been subjected to all the methods of test we then had available or knew something about. The wheel broke in a P80 aircraft that was flying at 35,000 ft. at about 585 mph.; one-half of the wheel was never found, and the other half was found six weeks later in a farm. The farmer who found it identified it as a piece of metal being sought and advertised for by Lockheed.

About that time we became quite interested in sonic testing of these

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forgings. G. M. C. research had considerable background with the Sonigage, and of course, the Sperry Reflectoscope was brought into the picture.

Since that time we have sonic tested in excess of 7000 I40 turbine wheel forgings. There is no known record of any forging that has passed sonic test of ever having failed, either in a spin test, or in an airplane.

We believe we have learned something as the result of this, the main thing being to establish with our several vendors the fact that we were going to use this method of test as a "Go and No Go" Gage.

We use $2\frac{1}{4}$ megacycles, at both half gain and full gain, with $\frac{1}{2}$-in. and 1-in. crystals, longitudinal and diametral searches, and inspect horizontally through the hub and hub areas where possible. Last year we took 21 wheels that had been rejected by the sonic standards that we have set up and instituted a joint investigation to determine the efficiency of our sonic test. This investigation included the steel producer, the forger and Allison.

The wheels were rejected either because of loss of reflection due, primarily, to structural non-homogeneity, or through indicated flaws. Of the 21 wheels so inspected, in 20 of them we found the reasons for the indications shown by our sonic test, within $\frac{1}{32}$ in. of areas indicated throughout any section in which they had been located by original search.

In only one were we unable to prove definitely the reason for adverse sonic test results, with the possible exception that we had carbide segregations in one portion of the forging.

Today we are using that test also on all the magnesium impellers as well as the aluminum impellers that are used in those engines. Since we have put sonic test on impellers we have not had one single service failure of an impeller, either in spin tests, or in flight.

Now, to give you some idea of what the turbine wheels are doing, the present I40 wheel is operating at about 11,500 rpm. at 3000 ft. producing thrusts slightly in excess of 5000 lb., which is equivalent, relatively to 5000 hp. There are 54 buckets on the wheel, and each of those buckets is putting out more horsepower at 11,500 rpm. with a tailcone temperature of 1265 F. than the presently used Cadillac engine, incidentally, of which G.M.C. is quite proud.

The rim temperature on those wheels are approximately 1200 F., and the hub' temperatures run around 450 to 600 F. From this it will be seen that we have quite a bit of thermal and physical stress on that particular assembly.

In trying to find a method of test, it was necessary to go through a long series of foundational tests.

We can, today, apply the Sonigage with just the same test results on a turbine wheel forging as we can a Sperry Reflectoscope. The "Sonigage" is employed successfully, as is well known, in the making of steel-bladed impellers, especially the type with internal brazings, support struts and assembly parts to determine all kinds of variations, both in brazing quality and metal wall thicknesses.

Much work has been done to provide the principles of acceptance or rejection by sonic testing on these parts and which are only a few that we are putting in production.

We went through the stages of radium, gamma ray, and radiography, using the Roentgen type. We went through all methods of fluorescent and penetrant inspection for surface conditions and correlated those against considerable microscopic control.

In the first 3000 wheels we made for that particular engine, the forgings were all made from electric furnace ingots from which we got approximately seven pieces per ingot for available forging stock. The ingots were reduced by forging, and after we had gone through less than 1500 wheels we found that it was useless to try to continue to put into good forgings, what is called the bottom portion of the ingot. So we eliminated the bottom portion as a direct result of the correlation of those tests. Sonic testing was a major factor in making that decision.

Today we are using not a conventional process for making our ingots at all, but a method of arc melting, whereby we get away from all major ingotism, and as of now, the sonic test results for the last 3000 to 4000 of the forgings that we have had, have shown less than 2 per cent rejection for any type of sonic defect, whether it was loss of reflection, which is entirely structural, or because of flaws which were indicated by direct readings and locations.

In testing wheels made from billet stock prepared from conventional electric furnace ingots, the smallest rejection that we have had ran in the neighborhood of 7.5 per cent to as high as 16 per cent. The vendors who are making parts for use have cooperated in the sonic test program. After proof of the fact that we could differentiate and show the types of defects that were in our parts, it has been a very agreeable approach to the subject.

The magnesium is still offering some problems and certainly the aluminum has been a serious problem, but my original statement should be kept in mind that since we have inaugurated those tests, we have had no flight failures. The other day we had one of our planes take off from Indianapolis with a brand new pilot, a young man who was sent out by the air frames company to test this new ship with the new engine in it, and he had never flown over the Middle West. He took off in Indianapolis and after some initiation flying, he was going to make a few tests at about 43,000 ft. He climbed steadily after leaving the Indianapolis Airport, and 18 min. later he called up and said, "Where in hell am I? I am climbing at 38,000 ft. and when I look out I can't see anything but water."

We finally located him just north of Chicago.

Now when you dash through the air at that speed, you can't have things flying apart, and if sonic testing is going to help us, let us have sonic testing!

MR. P. K. BLOCH.[3]—While our ultrasonic instruments have been used mostly for corrosion inspection, some oil refineries, chemical plants and shipyards have used them successfully to locate laminations in sheets.

Atomic hydrogen generated during a chemical process penetrates into the lamination and builds up sufficient pressure to form blisters and occasionally rupture the plate. Since this condition is frequently not visible from the outside, ultrasonic inspection instruments are used to locate laminated areas and measure the remaining metal thickness.

Laminations are occasionally present in steel plates used for shipbuilding. When the lamination is visible it the edge of the plate, it is necessary to determine its area. Formerly this was done by shearing the plate at intervals, until the end of the lamination was reached. In ultrasonic inspection, a quartz crystal is slid over the oiled surface, and the exact contour of the lamination is determined rapidly.

Another application has been the bonding of lead to steel on lead-lined process equipment. This application appears to be similar to the babbitt-lined brakeshoes mentioned earlier. The crystal is applied to the steel side. If the bond is good, the thickness indications for the steel are extremely weak, due to damping of the ultrasonic waves. If the lining is not bonded, beneath the point of crystal application, the thickness indications are very strong.

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