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A TEST TO ASCERTAIN THE TURBINE BLADE TEMPERATURE PROFILES ON A W2/700 ENGINE USING DIRECT WATER SPRAY COOLING

by

K.R.F. KENWORTHY

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THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.
A Test to Ascertaining the Turbine Blade Temperature

Profiles on a 12/700 Engine using Direct Water Spray Cooling

- by -

K.H.J. Kenworthy

**Summary**

Considerable information has been obtained with this method of cooling in a 12/700 engine on the spanwise distribution of temperature in the turbine blades. Previous reports have recorded the changes in temperature at nominal 50% chord at several radial stations.

In order to investigate further the temperature distribution, both spanwise and chordwise, a series of tests was made using "indicator" blades of Silver Steel in the hardened condition. By running the blades in the engine they were tempered according to local temperature conditions and hence by using the hardness/temperature relationship of the material the temperature distribution over the whole of the blade surface was determined. Engine speed was limited to 15,000 r.p.m. from stress considerations.

The tests have shown that with a flow of water, sufficient to reduce the leading edge temperature by 300°C, the trailing edge is at temperature approximately 100°C higher.

By suitable disposition of the water jets it should be possible to achieve uniform cooling, if required, along the length of the blade within 100°C.

Under normal running conditions at 15,000 r.p.m. without cooling the variation across the chord is less than 60°C.
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1.0 Introduction

To conclude the series of tests on the T2/700 engine using direct water spray for turbine blade cooling, a complete blade surface temperature pattern was required. Three alternative methods presented themselves for obtaining this information:

(a) The extensive use of thermocouples and slip rings

(b) The use of thermo-sensitive indicator paints

(c) The use of thermo-indicator materials

There are objections to all methods and finally (c) above was chosen for the following reasons. The use of thermocouples would entail far more tagging than could be at present used with existing slip ring pick-ups. If thermo-sensitive paints were used then a painted pilot rake complete with appropriate thermocouples would have to be fitted, before and after the turbine, to correlate colour/temperature changes, and in addition, the inclusion of water in the gas stream was an unknown factor in relation to the sensitivity of the paints. Also it was believed that the water would tend to remove some of the paint. This left thermo-indicator materials as a possibility. In this connection some experience had been gained, using Treble Super Monarch, Durahete and Silver Steel in pellet form for different temperature ranges, and obtaining the temperature from their respective hardness/temperature relationships. To obtain the maximum information, it was intended to use blades made of each of these materials, as between them practically the whole range from 200°C to 750°C could be covered. On rig testing, however, it was found that Silver Steel was the only material suitable from strength considerations. The Treble Super Monarch and Durahete were incapable of being run under centrifugal loads corresponding to their appropriate hardness/temperature ranges, Silver Steel was also subject to limitations as the following table will indicate.

<table>
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<tr>
<th>Temperature °C</th>
<th>Stress Tons/sq.in.</th>
<th>Elongation</th>
</tr>
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<tr>
<td>450</td>
<td>14.5</td>
<td>1% after 2½ hrs.</td>
</tr>
<tr>
<td>550</td>
<td>15.0</td>
<td>1% after 12 hrs.</td>
</tr>
<tr>
<td>600</td>
<td>5.0</td>
<td>1% after 4½ hrs.</td>
</tr>
<tr>
<td>700</td>
<td>12.5</td>
<td>16.26% after 10 hrs.</td>
</tr>
</tbody>
</table>

The composition of the Silver Steel used was as follows:

- Carbon: .95 to 1.05
- Sulphur: .025
- Silicon: .03 {max}
- Nickel: .15
- Chromium: .10
- Manganese: .15 to .25
- Phosphorus: .020
The centrifugal stress in the HJ/700 turbine blade is 12.5 tons/sq.in. at 7500 r.p.m., at a blade temperature in the high stress region, of 700°C. This meant that the blades could not be run at full speed except possibly under maximum cooling conditions. The tests were therefore done at conditions giving 9.0 tons/sq.in., an 600°C, corresponding to a speed of 15,000 r.p.m., at 500°C jet pipe temperature. It was anticipated that no-water condition could be obtained at this speed as a basis for comparison.

4.0 Method

The blades were made by standard procedure from a 2 x 1 in. Silver Steel bar (all pieces for machining being obtained from the same forging) and machined from the solid. The material being worked in the hot condition to final dimensions. The blades were hardened in their finished polished state by water quenching from 760°C followed by a low temperature temper at 175°C for 15 minutes in an endeavour to eliminate cracking. This unfortunately was not completely successful and a wastage of about 60% was incurred due to surface cracks. Lastly in the high stress region, using to the sharp changes in section, oil quenching was also tried but resulted in the blades not achieving the required hardness. Twelve blades were finally accepted for testing and calibration of temperature versus hardness was obtained from the remaining unscriviable blades. Some variation of the hardness readings was anticipated on account of the non-uniformity of the blade section. Under the conditions of test i.e., 30 minutes at a steady temperature, it was found that the hardness readings near the thick root was about 30 points V.P.H. higher (about 12°C lower) than near the tip for the lower temperature range. At the higher temperatures the difference was less.

The blades were finally hand polished and hardness checked ready for running. One blade was mounted in the turbine case for each test, but before installation the tip was ground down (with angle coolant) to allow for any elongation which might occur, and tests were done with varying water flows from a maximum of 777 lb/hr, at an engine speed of 15,000 r.p.m., and 500°C jet pipe temperature. In this way, by starting at the high water flow end of the range a check on the growth of the blade could be made and, as the quantity of water was reduced, the tip could be rounded accordingly. The blade injection was measured, as is usual practice, over two or more points over the space of failure due to cracks extending from the indentations, consequently measurements were made "overall" (dimension "W" Fig. 1) and the elongation is referred to on this length throughout. The curves given in Fig. 3 do not therefore represent true strain. Ten tests were made at 15,000 r.p.m., and 500°C jet pipe temperature and two at 14,000 r.p.m., and 800°C jet pipe temperature, the latter to check on change in temperature profile.

Each test consisted of a run of 30 minutes from the on-speed condition. The blades were given the equivalent of an air quench in a shut down test (then used) and engine were run down simultaneously, the latter in the H.P. cock.

The mean evaluation outlet temperature calculated from jet 1 and turbine temperature in addition for 15,000 r.p.m., was 650°C.

The water injection system was similar to that used in previous tests (Ref. 1 and 2). Water was fed to the inner ends of four equally
spread across guide vanes and ejected from three small holes in the trailing edges of each.

After each run the blade was removed from the engine and again hand polished and marked off by means of a special jig and template, as indicated in Fig. 1 ready for hardness checking. The blade was then mounted in a jig for this operation and hardness readings taken, using a Vickers pyramidal machine, with a 30 kilogramme load, on each surface of the blade.

In Fig. 1 it may be noticed that the spanwise stations on the concave side of the blade are offset to those of the convex side. This was done so that V.P.H. readings made at the thinner section of the blade (leading and trailing edges and tip) would not be affected due to thinness of section or proximity of indentations on the reverse side (centre of impressions to be > 2½ times the diagonal from any edge, and thickness under test should be > 1½ times diagonal of impression).

3.0 Discussion

It will be appreciated from the number of V.P.H. readings required in Fig. 1 that a considerable mass of figures could be presented. To keep this note within a reasonable size only the plottings of four of the blades run at 15,000 r.p.m. are presented. The other blades fall into the general pattern and the two blades run at the lower speed had correspondingly reduced temperature profiles.

Figures 2 to 6 show the temperature profiles and water flows. This method of presentation has been chosen so that an overall picture of the blade temperature distribution may be easily seen. The measuring stations are shown equally spaced for clarity, the actual locations being indicated as percentages of chord and height. The temperature at any point is plotted vertically to the scale of 1 inch = 100°C. The chord line and blade height (Fig. 2) representing a datum of 205°C in each figure. Thus all vertical ordinates are measured values above 200°C.

In the uncooled condition (Fig. 2) it may be seen that there is very little temperature radiant across the chord at any blade height except near the tip where the trailing edge is at a higher temperature by approximately 59°C (1.2 × 48°C, trailing edge 63°C) on the concave side and 26°C (leading edge 44°C, trailing edge 47°C) on the convex side. This is in general agreement with Rout 9 although R.P.H. and temperature conditions are higher than those presented in this note (16,750 R.P.H. and 650°C Jet Pipe Temperature) and results are not directly comparable.

Fig. 3 shows the effect of passing 206 lb/hr. of water and the large drop in temperature (208°C) near the root leading edge on the convex side is apparent. This temperature drop is not so noticeable on the concave face, but it should be borne in mind that the sections are differently located on the two sides.

The remaining curves show the further extension of the cooled area of the blade with increased coolant flow, but it will appear that little cooling is being contributed by the usual dissipator subas (i.e., near tip). This is attributed to the pressure gradient near to the turbine annulus and to the resistance to flow of the liquid water. This effect is especially noticeable at the lower water pressures.
In all cases the convex sides of the blades are cooler at a greater extent than the concave. On Fig. 10 may be seen typical water marks on a Silver Steel blade which has run at a water flow of 185 lb/hr. This water indentation on the convex side is typical of all water flows and indicates the contributing of the water along the blade from the root. From the marks in this illustration it would be expected that towards the tip there would be a cooling region up the blade extending from the root leading edge towards the tip centre chord. This is confirmed by the temperature profiles of the convex side of the blades at the higher flow rates. Fig. 6 is an example of this and shows the drop in temperature towards 50% chord near the tip.

Fig. 7 shows the temperature of the convex and concave sides of the blade at 50% chord taken from the respective curves in Fig. 2 to 6 and shows more clearly the temperature difference through the blade section at any blade height.

As already noted, before running the blade tips were ground down to allow for possible growth and Fig. 10 shows, approximately full size, the difference between a blade before and after running. This particular blade had been run for 30 minutes at 19,000 r.p.m. with a water flow of 185 lb/hr, and shows the "mooing" which occurred and the resultant indentation. A plot of this indentation with varying water flow for all blades used in the test series is shown at Fig. 10. The indentation of the blades probably results in a reduced wear at initial high speeds but it is believed, to some degree, due to the operating temperature. This effect will be investigated in the near future.

The extent to which the temperature distribution is influenced by the thermal conductivity of the metal has not been determined. It is not considered however that the difference in this property between Silver Steel and a typical blade metal such as Nimonic 80 would materially affect the results.

4.0 Conclusions

It is shown that the overall temperature of the turbine blades may be considerably reduced by the direct water spray method of turbine blade cooling. Owing to the nature of the cooling some considerable temperature gradient may be expected across the chord and along the span of the lower water flow. Towards the higher flow ranges this effect is less marked and cooling becomes more even.

The tests have also shown that with a flow of water, sufficient to reduce the leading edge temperature by 300°C, the trailing edge is at a temperature approximately 100°C higher.

By suitable disposition of the water jets it should be possible to achieve uniform cooling along the length of the blade within 100°C or to vary the degree of cooling, if required, subject to this limitation.

Under normal running conditions at 19,000 r.p.m. without cooling water, the variation across the chord is less than 60°C.

The tests have also shown that a standard metal such as Silver Steel is capable of being used in a turbine for short periods if adequately cooled.
Acknowledgment

The writer wishes to acknowledge the valuable and tedious work, which has been done by Misses Heine and Norman in reading and transcribing the results.

REFERENCES

<table>
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<tr>
<th>No.</th>
<th>Author</th>
<th>Title etc.</th>
</tr>
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<tbody>
<tr>
<td>3</td>
<td>E. Gloucy</td>
<td>The use of Knoop steel pellets for the measurement of temperatures attained by turbine rotor blades during service.  Memorandum No. 41.97.</td>
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CIRCULATION

C.S.(A)
The Chief Scientist
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K.E.R.F./PM/290/7:10/24/51.
"h" for standard blade = 3.05"

Stations at \( \frac{1}{2} \) intervals along "h" from datum

Datum line bottom of blade platform

0.4" to first station (Convex side)
0.55" to first station (Concave side)

Chord stations

<table>
<thead>
<tr>
<th>Station</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>% &quot;c&quot; from leading edge</td>
<td>3.28</td>
<td>24.8</td>
<td>47.2</td>
<td>67.2</td>
<td>82.8</td>
<td>96.7</td>
</tr>
</tbody>
</table>

Blade chord

Leading edge

Trailing edge

Nominal "c" = 1.22"

Positions of V.P.N. readings on W2/700 turbine blades
TEMPERATURE PROFILES OF SILVER STEEL BLADES

AT 15,040 R.P.M. & 500°C JET
WATER FLOW = 0 LB/HR

CONCAVE SIDE

SCALE: 1 INCH = 100°C ABOVE DATUM

LINE (XX & YY) REPRESENTS 200°C

STEEL BLADES IN W2/700 WITH WATER COOLING

500°C. JET PIPE TEMPERATURE
WATER FLOW = 206 LB/HR
DELIVERY PRESSURE = 11 LB/SQ.IN
AT ENTRY TO GALLERY PIPE

TEMPERATURE PROFILES OF SILVER STEEL BLADES IN W2
AT 15040 R.P.M. & 500° C. JET PIPE
$w = 206 \text{ LB/HR}$

PRESSURE = 11 LB/SQ. IN.

TO GALLERY PIPE

CONCAVE SIDE

BLADES IN W2/700 WITH WATER COOLING

C. JET PIPE TEMPERATURE
TEMPERATURE PROFILES OF SILVER STEEL BLADES

AT 15,040 R.P.M. & 500°C. JET
WATER FLOW = 420 LB/HR

PRESSURE = 33 LB/SQ IN.

CONCAVE SIDE

CONTOUR

9/2 7/3 5/1 4/2 5/7 1/5 3/2 2/4 4/7 6/7 8/2 6/7

° BLADE HEIGHT

% CHORD FROM LEADING EDGE

WATER
FUEL = 24.8 %

STEEL BLADES IN W2/700 WITH WATER COOLING

500°C. JET PIPE TEMPERATURE
CONVEX SIDE

WATER FLOW = 616 LB/HR

DELIVERY PRESSURE = 35 LB/SQ.IN.

\[
\text{WATER FUEL} = 38.7\%
\]

TEMPERATURE PROFILES OF SILVER STEEL BLADES IN W2,

AT 15,040 R.P.M. & 500°C JET PIPE
LADIES IN W2/700 WITH WATER COOLING
JET PIPE TEMPERATURE
WATER FLOW = 797 LB/HR
DELIVERY PRESSURE 39 LB/IN

CONVEX SIDE

TEMPERATURE PROFILES OF SILVER STEEL BLADES

AT 15,040 R.P.M. & 500°C. JET P.I.F.

WATER FUEL = 50.2%
LOW = 797 LB/HR
PRESSURE 39 LB/SQ.IN.
CONCAVE SIDE

BLADES IN W2/700 WITH WATER COOLING
AT NOMINAL 15,040 R.P.M. 500°C. J.P.T.

AT NOMINAL 14,000 R.P.M. 490°C. J.P.T.

ELONGATION MEASURED ON OVERALL BLADE LENGTH "L" (FIG. 1)

DURATION OF TEST: 30 MINS
IN ALL CASES

W2/700 SILVER STEEL TURBINE BLADES

PERCENTAGE ELONGATION vs WATER FLOW
FOR GIVEN R.P.M.
HARDNESS TEMPERATURE CALIBRATION CURVE
FOR W2/700 SILVER STEEL TURBINE BLADES
W2/700 Silver Steel Blade before and after running at 15,040 R.P.M.

500°C Jet Pipe Temperature

And Water Flow of 185 LB/HR
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