Unsteady Temperature Measurements During Surge in a Highly Loaded High Pressure Compressor

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Abstract

To obtain an impression of the structural loads on compressor vanes due to the temperature peaks during surge unsteady measurements were performed in aerodynamic rig tests with a highly loaded HP-compressor.

In addition to the fast response static pressure probes three types of fast response temperature probes were used to measure the gas temperature during surge cycles as well as the vane surface temperature at different locations along the whole compressor.

This paper gives a description of the type of probes used, their arrangement and the data evaluation. Furthermore some typical results of measurements during surge are shown and the good and bad experiences are discussed.

Introduction

During the last years several investigations concerning surge in compressors have been performed. Most of these investigations were done in low speed compressors with a blading of high aspect ratio. Modern compressors are usually highly loaded and the blading is therefore often of wide chord type. So it was of interest to get information about the surge phenomenon in such a type of compressor.

In fig. 1 one surge cycle is schematically plotted in a compressor map (pressure ratio versus airflow rate) with one speedline. At the beginning the compressor is operating on this stable speedline. By closing the throttle the compressor ratio increases while the flow rate decreases up to a critical value. At this point one or more blade rows stall and the compressor surges. It is typical for a highly loaded compressor to surge in his high speed range. This surge consists of four characteristic periods:

During the first period the airflow comes to a stop within 2 to 10 ms.

In the second period the direction of the airflow changes due to the volume stored after the compressor. This volume will blow out, one part through the compressor and the other part through the exit throttle. The duration of this reverse flow depends on the extent of this storage. For the compressor examined this time is about 400 ms.

During the third period the flow becomes stable again and the compressor jumps back on his stable characteristic.

Due to the setting of the throttles the compressor will increase his pressure ratio during the fourth period. Now, if the setting of the throttles is still unchanged the same surge cycle starts again.
The interesting period now is the reverse flow.
What happens during this reverse flow?

On fig. 2 two stator rows and one rotor row are schematically plotted. During the reverse flow the airflow leaves the stator vanes with their metal inlet angle. Superposing the rotational speed of the rotor, it can be noticed that the flow hits the pressure side of the blades in the trailing edge region normal and this with a high Mach number. This high Mach number results from the high rotational speed of the rotor. Concerning the next stator vanes, the same flow behaviour occures.

Now, what is the effect of this flow behaviour?

This flow behaviour results in a high structural loading of blades and vanes, showing cracks at the trailing edge due to torsion. Also a high temperature loading of the thin trailing edges occures. This temperature loading results in a tempering of the thin trailing edges.

Knowing these phenomena the objectives of this investigation were defined as follows:

firstly measuring the total temperature rise during surge

secondly determining the air flow rate during surge

This paper presents the first point, only .

These investigations were performed in a five stage high pressure compressor with a pressure ratio above 6 (see fig.3).

The temperatures were measured at three different axial positions, at the inlet, on the pressure side of stator one and on the pressure side of stator three. At the inlet the gas temperature were measured with a purchasable temperature probe and with a conventional mineral insulated thermocouple. On stator one these conventional mineral insulated thermocouples were used.
On stator three a foil thermocouple was employed for the first time to measure the surface temperature. All thermocouples used were of type K (chromel-alumel). Due to this conventional thermocouples also the data aquisition and evaluation was conventional.

Description of the temperature sensors

1. Temperature probe

On fig. 4 the head of this temperature probe is shown. A comparison with the match gives an impression of the size. This probe is manufactured by Medtherm Co. US and so in the following this probe is called Medtherm probe. On this figure the fine thermocouple wires are pictured. These wires have got a diameter of about 25 micrometer. In this probe large thermocouple wires with a diameter of about 0.25 mm are swaged with magnesium oxide insulation within a stainless steel sheath. The ends of the wires are flattend and .125 mm dia. holes are drilled through the flattend ends. Each fine wire is then welded to the appropriate large wire, coiled around it, passed through the drilled hole and fusion welded at the hot junction. With this construction the fine wire can be bent or vibrated without weakening the welded connection of the fine wire at its weld to the large wire. This feature should assure a longer life for the fine wire thermocouple than a conventional welded connection.

2. Mineral insulated thermocouple

Fig. 5 shows the instrumentation on the pressure side of the first stator. The thermocouples used are mineral insulated thermocouples in stainless steel sheath with a sheath diameter of 0.25 mm. The hot junction of the thermocouple wires are fusion welded with the sheath. The thermocouple tubes are wrapped along the leading and trailing edge to reduce temperature gradients in the sheath. The tubes are spot welded with small metal sheets to the surface and the last 2 mm of the sheath are bent from the surface to measure the gas temperature.

In this example the gas temperatures were measured near leading and trailing edge at two radial positions respectivly.

The same mineral insulated thermocouples were also used in the inlet of the compressor as comparison to the Medtherm probe.

3. Foil thermocouple

Fig. 6 shows the third temperature sensor investigated. This foil thermocouple type k was selected to measure the surface temperature rise during reverse flow. The manufaturer is Omega US. The fixing of the hot junction is as follows:
A first polyimide foil is glued on the clean surface for thermal insulation of the foil wires. In the region of the measurement position a hole is punched into this foil. The foil wires have got a foil thickness of about 0.013mm and are positioned so that the hot junction could be pressed into this punched hole to get contact with the surface. A second polyimide foil is glued to fix the wires and also for thermal and mechanical insulation.

The example on this figure shows the instrumentation on the pressure side of stator three. There are two foil thermocouples and two mineral insulated thermocouples arranged to measure the surface and gas temperature near trailing edge and stagger axis.

Response time

The aim of this investigation was to measure the temperature rise during reverse flow as described in the introduction. So it was necessary to select thermocouples with a response time much shorter than the duration of the reverse flow. On fig. 7 the response times of the mineral insulated thermocouples and of the Medtherm probe versus airflow velocity are shown. These measurements were performed under ambient pressure and temperature conditions in a small windtunnel.

As it was expected the response time of the Medtherm probe is by a factor of ten shorter than that one of the mineral insulated thermocouple. At airflow velocities above 80 m/s the response time of both sensors are nearly constant. In this range the response time of the Medtherm probe is about 10 ms and that one of the mineral insulated thermocouple about 100 ms. These measured values are in good agreement with the response times declared by the manufacturers.

The response time of the foil thermocouple was not determined. The manufacturer declares this value to be about 5 ms.

Results

With the instrumentation described, it was possible to determine the temperature rise during surge, successfully. According to the pertinent literature this was the first time that the temperature rise (gas-and surface temperature) during surge was measured between the stages.

Fig. 8 contains some typical results measured in the compressor inlet. One surge cycle is shown. The four tracks are

inlet pressure, exit pressure

mineral insulated thermocouple and Medtherm probe

Time is increasing from left to right. This figure can be devided into three periods. Firstly, the closing of the exit throttle putting the compressor to surge, secondly the reverse flow period and third the recovery period. During the reverse flow the exit pressure decreases continously to a minimum, while the inlet pressure increases rapidly to a nearly constant value. The minimum in the exit pressure defines the end of the reverse flow and then the recovery starts. In this example a second surge cycle occured on a low pressure level.

The scale of both temperature tracks is the same. In the first period both probes show the same ambient temperature. When the compressor surges both probes show the rise in temperature. The gradient of the Medtherm probe is much higher than that one of the mineral insulated thermocouple and also, due to the shorter response time, the maximum indicated is higher by a factor of 1.7.

The temperature curves plotted in this figure are the measured values only, without correction using the measured response times.

During the recovery both probes show the same ambient temperature of the normal inlet air flow.

Conclusions

The experiences were classified into negative and positive experiences.

Foil thermocouple:

The mechanical resistance of these foils due to the fixing used is very poor. Fig. 9 shows these foils before test on the left side and afterwards on the right side. Please remember the velocity triangles showed in fig. 2. During reverse flow the region near trailing edge is the most critical one due to the high Mach number and temperature loading. Fig. 9 gives the confirmation. The second polyimide foil is melted due to the unexpected high temperature loading.

In spite of these sensors being very low-priced, they are the loser in this investigation because of the very high costs for their application.

Mineral insulated thermocouple:

A negative point is the high response time. Just in the case described in this paper the response time is acceptable to get a rough mean value, but if the duration of the reverse flow is much shorter these thermocouples are too slow. They show a very high mechanical resistance, are easy to fix on surface or in probes and the price is acceptable.

Medtherm probe:

The Medtherm probes have nearly the same advantages and disadvantages as the mineral insulated thermocouple. At high Mach numbers they are suspectible to the rapid flow reversal during surge. But they are quite cheap, they are very easy to fix in probes and the response time is also acceptable for shorter reverse flow measurements.

Ackknowledgements

The authors wish to thank Mr.Dumrauf from the instrumentation group for the application of the sensors.

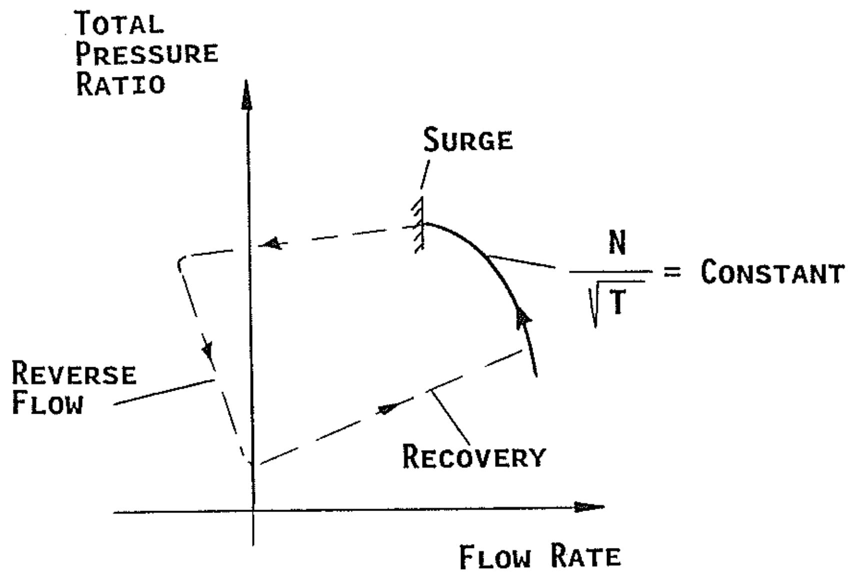


fig. 1: surge cycle schematically

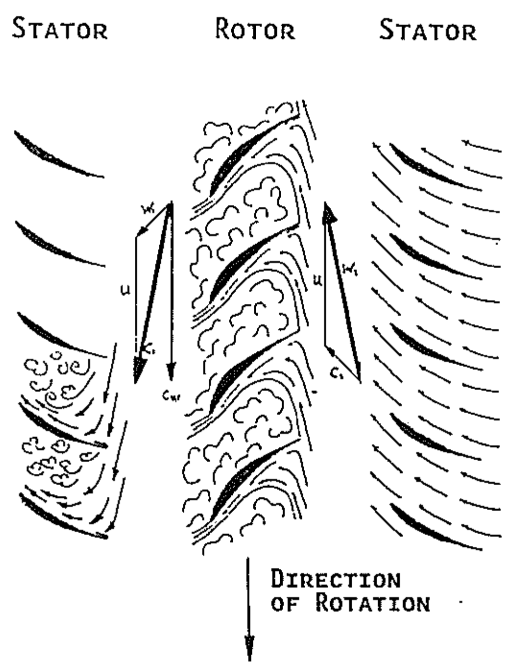


fig. 2: velocity triangles during surge

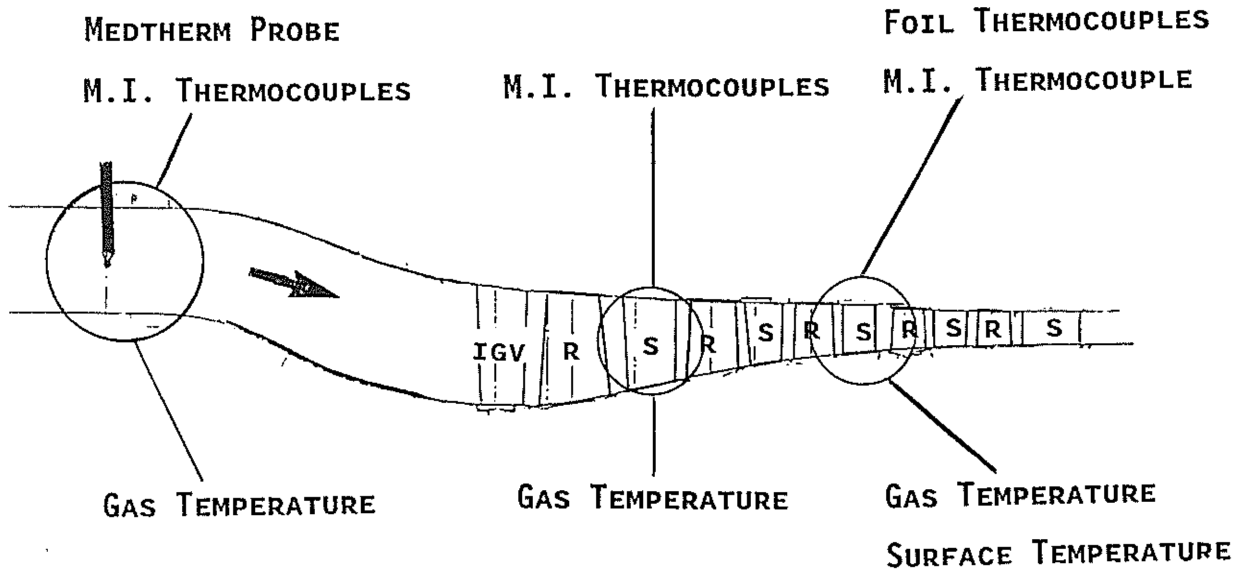
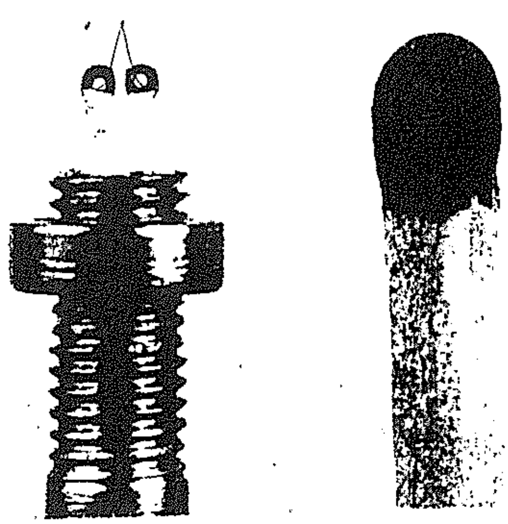


fig. 3: measurement-positions of thermocouples



MANUFACTURER : MEDTHERM

TYPE : 202-02K10CZ12-454

WIRE DIA. : 25.4 μM

fig. 4: metherm-probe

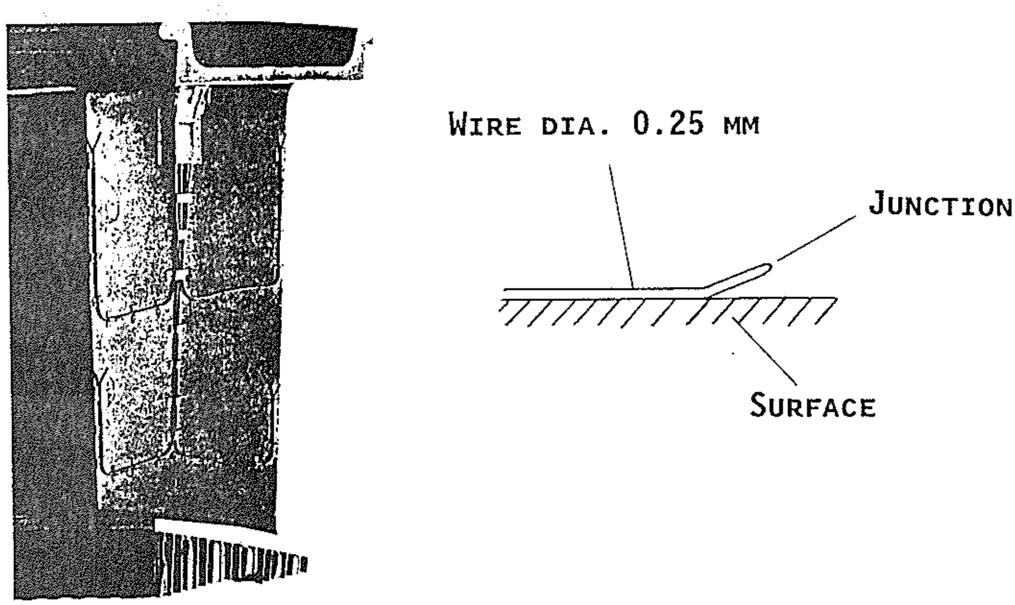


fig. 5: mineral insulated thermocouple

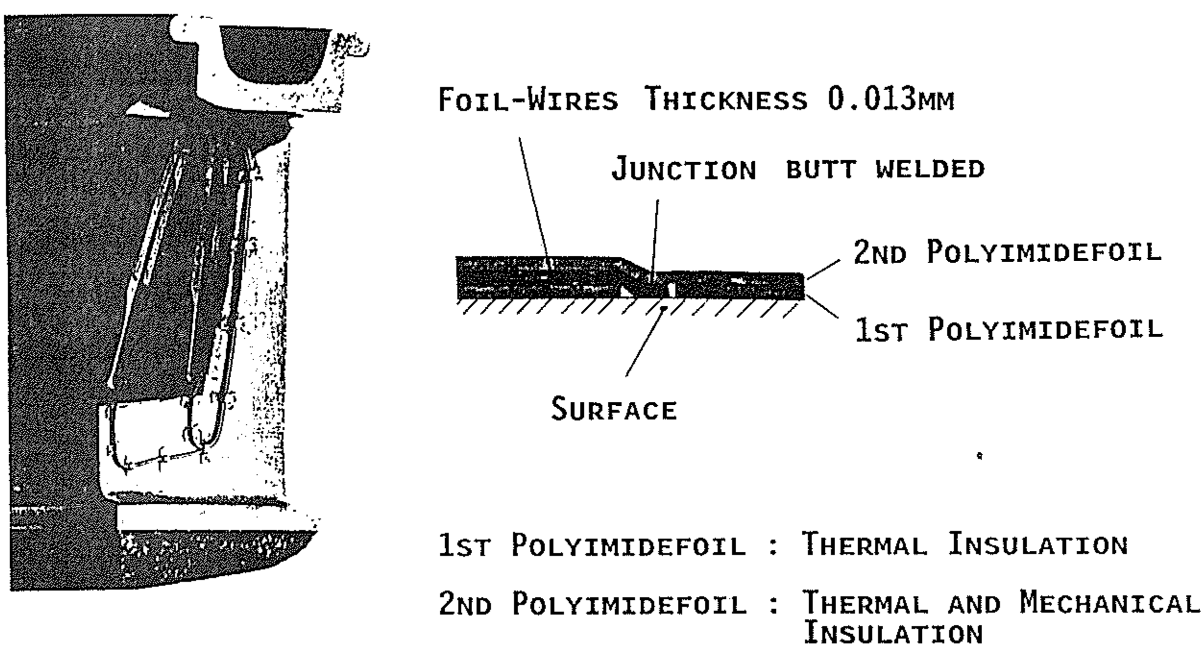


fig. 6: foil thermocouple

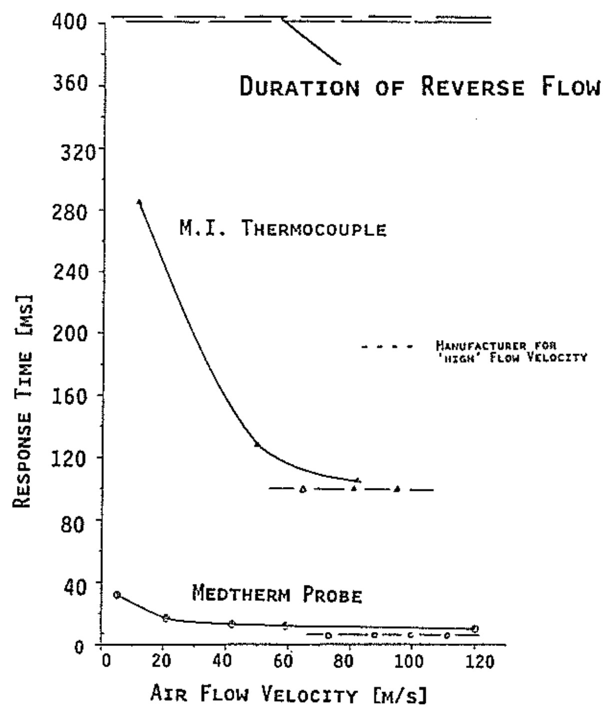


fig. 7: response time versus air flow velocity

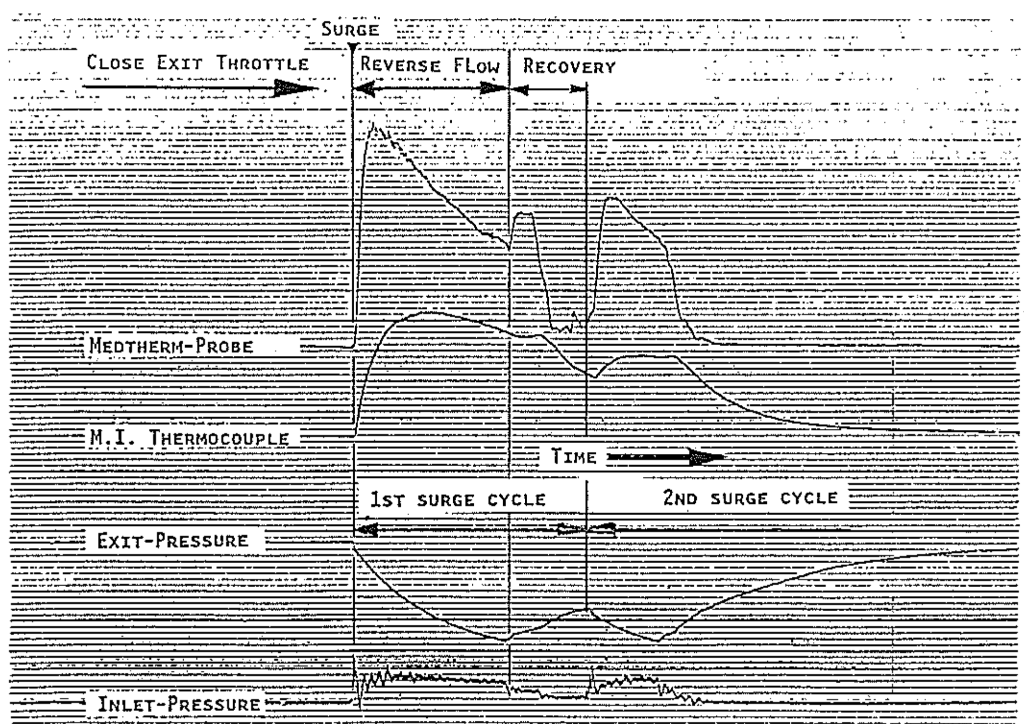


fig. 8: measured surge cycle

BEFORE **AFTERWARDS**

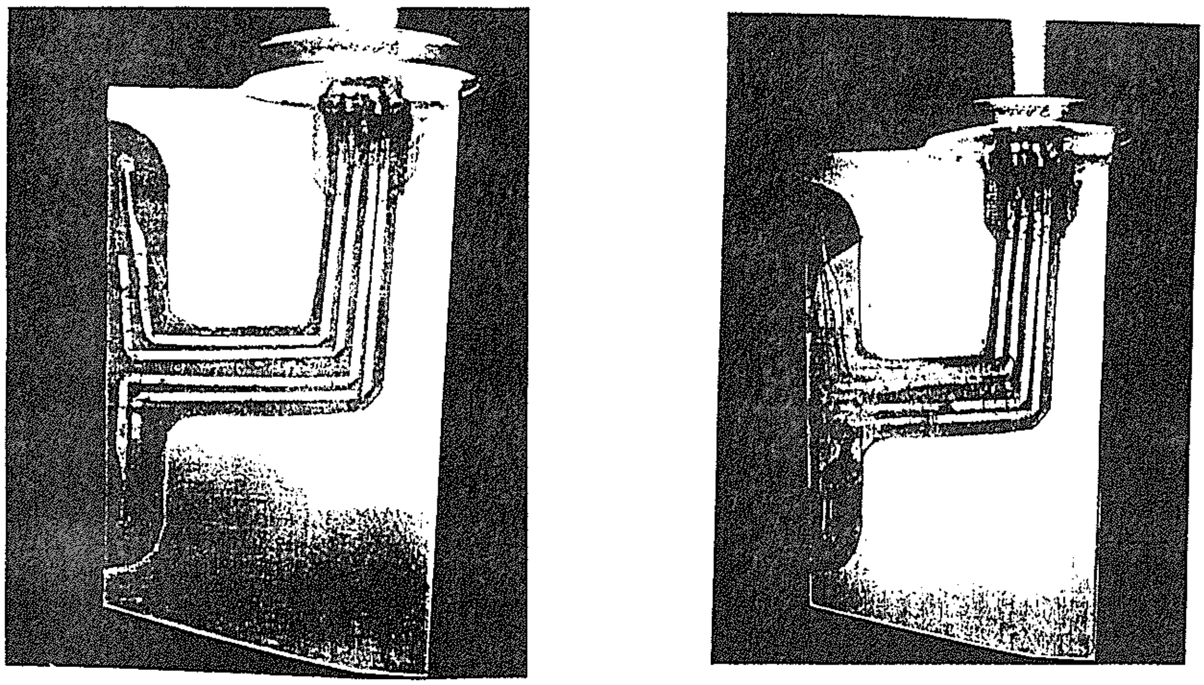


fig. 9: foil thermocouple before test and afterwards