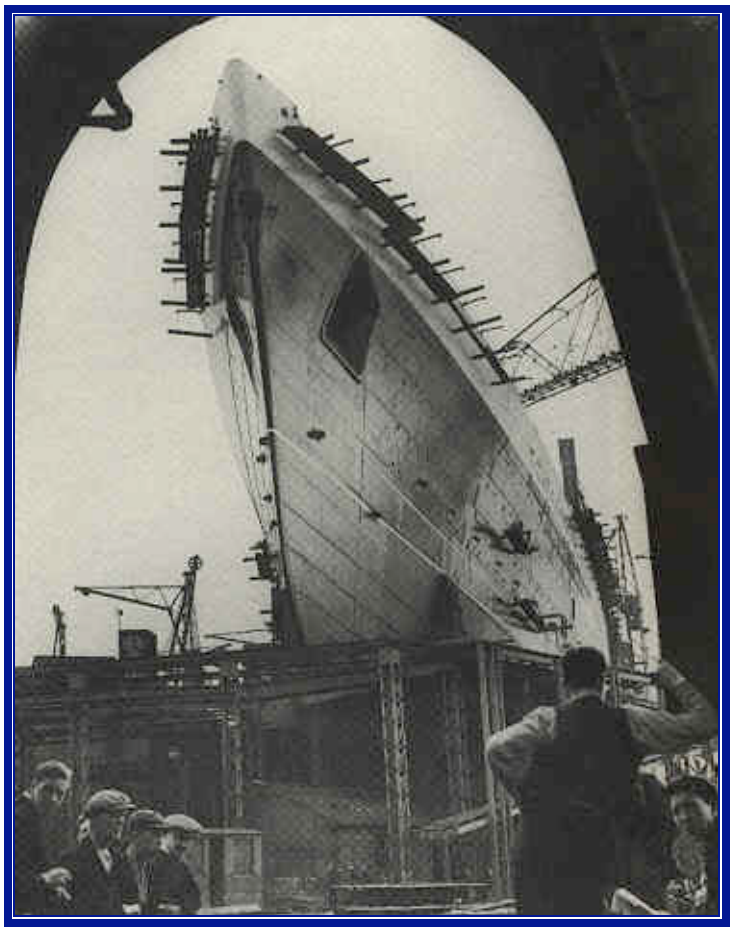
MARINE AIR CONDITIONING



R M S Queen Elizabeth

Tests on refrigeration plant, July 1939

Report by Carrier Engineering Company

00361

TEST DOPE 2(a)

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WFS/HC
R.AC. 5806.

3rd July, 1939.

R E P O R T.

SHIP No. 552.

TESTS OF REFRIGERATION PLANT

Our Order No. E 6045/5806.

DESIGN AND MANUFACTURE

The main parts of the above plant were manufactured by The Mirrlees Watson Co. Ltd. Scotland Street, Glasgow, to our specification.

DUTY OF PLANT

Steam (dry saturated) at vapour compressor nozzles	.....	200 lbs.
Condenser vacuum	.....	28" Hg. with a barometer of 30" Hg.
Chilled water quantity	.....	1410 g.p.m.
" " inlet to flash chamber	..	51.5° F.
" " outlet from flash chamber		46.0° F.

(This represents 4,670,000 BTU/hr.
= 389.1 tons refrigeration (12,000 BTU/hr/ton))

The complete plant has the flash chamber divided into three sections, each section being operated by one set of vapour compressors.

For the tests to be described, a tank representing one chamber only was used, being operated by one set of vapour compressors. Therefore the output looked for was one third of the total given above, thus :-

Steam (dry saturated) at vapour compressor nozzles	.....	200 lbs. per sq. in. gauge.
Steam consumption	.....	3600 lbs/hr. max.
Condenser vacuum	.....	28" Hg. with a barometer of 30" Hg.
Chilled water quantity	.....	470 g.p.m.
" " inlet to flash chamber	..	51.5° F.
" " outlet from flash chamber		46.0° F.

(This represents 1,557,000 BTU/hr. = 129.7 tons refrigeration (12,000 BTU/hr/ton)).

GENERALLY

The main object of the tests was to obtain the specified output under specified conditions. Such result was not easily arrived at.

After the specified output was obtained, it was intended that other tests should be made, which will be described later in this report.

As the tests proceeded it became evident that it was not going to be possible to obtain figures of such accuracy as had perhaps been hoped for. This was due in the main to the impossibility of maintaining a constant steam pressure, as the boiler was not capable of producing the required weight of steam at the specified pressure. This resulted in constantly varying pressures with the boiler constantly steaming at its limit consequently each variation in stoking was reflected in the steam gauge. In addition to this, steam was taken at times for other purposes (sometimes without warning) and several breakdowns also occurred.

It was also noticeable that a thermal lag existed in all the heat cycles, particularly the condenser.

The method of measuring the quantity of condensate shewed itself as the tests proceeded to be not too reliable.

Many hours were spent in running the plant to obtain the steadiest possible conditions before log readings were taken.

TEST LAY-OUT.

The original test lay-out was as shewn by Drawing No. 5806/79.

This arrangement was modified as the tests proceeded as indicated later in this report.

INSTRUMENTS.

Before the tests and at frequent intervals thereafter the thermometers were calibrated. The positions of certain thermometers were regularly reversed as a check (notably thermometers in chilled water circuit)

The two absolute pressure gauges (flash chamber and condenser) by Mirrlees Watson developed faults, although they checked one against the other before the tests were commenced. They were

later substituted by gauges manufactured by W. Edwards & Co. and provided by us and although the first instruments supplied were unsatisfactory, the final pair gave accurate and reliable readings. They were constantly checked one against the other as the test proceeded.

Condensate was measured by a nozzle device which is a standard of Mirrlees Watson. It is shewn on their drawing No. P.D. 8541/C (Attached). A gauge glass, not shewn on the drawing, indicates the height of water over the orifice.

The quantity of chilled water circulated was measured by a nozzle device manufactured by Electroflo Meters Co. Ltd. (details on Refrig. Reports File). This instrument shewed g.p.m. by a mercury column against a scale. The makers instructions as to fitting were obtained and the instrument checked.

The mercury column at first fluctuated considerably but this was remedied by the fitting of a perforated plate in the extraction pump discharge and, mainly, by carrying a higher water level in the flash chamber, thus increasing the pump suction head and reducing cavitation.

The amount of condensing water was given by Mirrlees Watson's venturi meter. It is in constant use by them and they guaranteed its accuracy. There were no means of checking it.

The load steam was measured by an orifice, gauges and thermometer, the quantity of steam being calculated from Goudie formulae. This steam measuring device is shewn on Mirrlees Watson's drawing No. C 20473. Reference to the log will result in the accuracy of the device to be doubted.

Steam to the vapour compressors was calculated by Goudie formulae.

Figures for all steam calculations were taken from "The 1939 Callendar Steam Tables".

MAKERS' TEST.

In spite of much urging, the manufacturers could not be brought to the point of stating definitely they were ready for the tests to begin.

To crystallise the position, the writer was instructed to attend at their works on 2nd March 1939 and was shewn their log demonstrating an output 55% of the specified output.

A detailed report of this visit with their logs is in Refrig. Reports File.

It was judged from the information submitted by Mirrlees Watson that the failure lay in great part in the method of spraying the chilled water in the flash chamber having in mind Mirrlees Watson's assurance (both verbal to the writer and by letter 18th February 1939) that the vapour compressor had under test shewn itself capable of dealing with the specified volume of vapour.

This test they had made by admitting steam into the flash chamber when a pressure of 6 m.m. (39° F.) was maintained, when the full volume of vapour was handled.

Immediate steps were taken by us to have fitted in the flash chamber special spray nozzles made by Korting Bros. of Nottingham. (The original basket sprays by Mirrlees Watson are shewn on their drawing No. C 22268 and the final arrangement with Korting nozzles on their drawing No. C 25546).

The matter of this amendment and the counter suggestion of Mirrlees Watson's is dealt with in detail by the writer's report (9th March 1939, Refrig. Reports File) of his visit to Glasgow on 7th and 8th March.

Mirrlees Watson's alteration to water sprays failed ~~in~~ to increase the output of the plant and preparations were made for fitting the Korting nozzles; see also reports on file dealing with tests of these nozzles.

OUR TESTS (Log Sheets A, B, C & D. Reports 27th, 28th 29th & 30th March 1939)

The plant was ready for test on 27th March 1939.

The flash chamber was fitted with Korting nozzles and the vapour comprised a single nozzle, see drawing No. 5806/72 "Queen Elizabeth. Mirrlees Watson. Single Nozzle Test." Compressor

See also Log Sheets A, B, C & D dated 27th, 28th, 29th, 30th & 31st March 1939 and reports of 28th, 29th & 30th March on Refrig. Reports File.

Output was increased to 61% of duty by the introduction of the Korting spray nozzles.

As a result of these tests attention was directed by us to the value of the single vapour compressor nozzle and I again saw

Mr. Dexter of Mirrlees Watson on 4th April, handing him Mr. Sainty's letter of the 3rd April with reference to multiple nozzles in place of the single one. (See writer's reports 4th and 5th April).

It was decided however to conduct our own test with load steam on the flash chamber before removing the single nozzle in order to demonstrate its capacity as by this time we felt justified in doubting any results other than those obtained by ourselves.

OUR TEST (Load steam on flash chamber. Log Sheet E, 7th April 1939)

The results of this test shewed that the Mirrlees Watson single nozzle was not capable of dealing with the volume of vapour which would be produced in the flash chamber under specified conditions. Mirrlees Watson were alarmed.

It should be stated here that they had been convinced that the single nozzle was an improvement on the multiple nozzle and that they had spent considerable time in making and testing multiple nozzles for this contract with the result that they had been discarded. (See their letter of 4th April 1939). Although alarmed, they were inclined to attribute the failure of the single nozzle to any of a number of causes rather than discard their opinion. They finally did lose faith in the single nozzle when towards the end of the tests the single nozzle was again tried out without success. (See later in this report).

However, after the above test they agreed to go back to the seven nozzles they had discarded and the plant was again ready for test on 21st April 1939.

The method of making the steam test mentioned above was as follows:

The chilled water outlet from the flash chamber was disconnected from the extraction pump and blanked with a flange. The flash chamber was filled with water to a level of 2 ft. A steam pipe was entered into the flash chamber through the blank flange terminating in a steam distributor under the level of the water.

Log Sheet E shows that at a flash chamber temperature of 47° F. the compressor could deal with vapour representing only 1,358,000 BTU/hr.

(With flash chamber temperature of 57.5° F, the compressor eliminated 1,465,000 BTU/hr.)

OUR TEST (Log Sheet No. 1. 21st April 1939)

This was an output test under as near specified conditions as possible.

The compressor consisted of seven nozzles as shewn on drawing No. 5806/72 "Queen Elizabeth. Mirrlees Watson. 7 per set." and arranged in the air inlet box as shewn on drawing No. 5806/71 "Mirrlees Watson".

80 Korting spray nozzles were fitted in the flash chamber.

An amendment to the arrangement of the plant was made before this test was begun in view of the difficulty of the steam supply. In order to concentrate all available steam on the compressor, the load steam was cut out and the chilled circulating water temperature was adjusted by means of a bleeder from the condenser water outlet, whilst another led from the chilled water to the sump supplying the condenser water.

Although this arrangement made the plant more difficult to handle (control of chilled water temperature) it resulted in improved conditions at the compressor. In addition, the steam superheater was removed from the supply line and an additional separator added. The subsequent tests were therefore judged to be carried out by dry saturated steam. Even so, the steam supply remained a difficulty.

With a steam pressure varying between 190 and 198 lb/sq. in. the mean output recorded in this test rose to 1,524,600 BTU/hr. which represented 98.4% of the full duty.

This was considered to be satisfactory and preparations were put in hand for the next test.

OUR TEST (Log Sheet No. 2. 22nd April 1939)

The object of this test was to determine the maximum compression ratio at which the machine would operate without failure.

(According to Mirrlees Watson's Tender Data Sheet, the flash chamber vacuum would be 29.7 in. Hg. and the condenser vacuum would be 28.0 in. Hg. (Bar. 30").

29.7 in. Hg = 45° F. = 0.1471 lbs. abs.
28.0 in. Hg. = 101° F. = 0.9757 lbs. abs.
= 6.633 compression ratio)

Log Sheet No. 2 referred to above, shews that with a compression ratio of 7.91 the compressor "broke", but the steam pressure had at that moment dropped to 180 lbs. Holding other conditions as

stable as possible, effort was made to increase the steam pressure and at 195 lbs. steam, the compressor picked up with a compression ratio of 7.236 and continued to function. At a point between a compression ratio of 7.236 and 7.82, the compressor broke momentarily, immediately recovering however and continuing until a compression ratio of 8.23 was reached when a definite and final "break" occurred.

In order to increase the compression ratio, the condenser absolute pressure was increased by means of decreasing the quantity of cooling water and also by the admission of air to the condenser. The consequent increase of condenser water outlet temperature made it difficult to maintain constant chilled water inlet temperature to the flash chamber and it will be seen from the log that these temperatures were subject to fluctuation.

It may be judged from this test that the vapour compressor is stable up to a compressor ratio of 8.0, which represents a condenser pressure of 1.1768 abs. = 107.5° F. As the condenser makers state that with condenser circulating water inlet at 83° F. the condenser temperature will be 101° F. it may be assumed that the vapour compressor will operate with condenser circulating water inlet up to 89.5° F. approximately.

(For certain reasons (see report in Refrig. Report File) the writer did not consider the output figures given by chilled water on this job to be reliable and the test was repeated at an early opportunity, see Log Sheet No. 3.)

OUR TEST (Log Sheet No. 3. 25th April 1939)

This test was a repeat of that recorded by Log Sheet No. 2.

The output by chilled water can be taken as correct, but the compression ratios did not have such close attention by the writer as obtained in the previous test. Nevertheless, the compression ratio of 8.0 as the breakdown point would appear to be confirmed.

OUR TEST (Log Sheet No. 4. 26th April 1939)

During the period of uncertainty which ruled at the time, Mirrlees Watson's single nozzle was under test we ourselves designed a multiple nozzle compressor. This nozzle is shewn on drawing No. 5806/72 "Queen Elizabeth. Carrier Test Nozzle" The design was based upon those in service on board "Queen Mary", for detail of which see drawing No. 5806/72. Seven of the new nozzles were fitted in the air inlet bore as shewn on drawing No. 5806/71 (Log Sheet No. 4).

The output obtained by this design was 66% of the full duty as against 98.4 % by the Mirrlees Watson multiple design, but it will be noted that the steam consumption was reduced.

OUR TEST (Log Sheet No. 5 27th April 1939)

It was considered that the results given by the previous test could be improved upon by bringing the nozzle outlets nearer the entrance to the compression cone.

Accordingly, the arrangement was altered to that shewn on drawing No. 5806/71 (Log Sheet No. 5) and the test repeated.

The output obtained was 62.3% of the full duty, again with reduced steam consumption.

OUR TEST (Log Sheet No. 6. 27th April 1939)

In view of the two previous results, the opinion was formed that the maximum output from this compressor design would be obtained with the nozzle exits fixed somewhere between the first and second test positions.

Accordingly, the nozzles were re-arranged as shewn by drawing No. 5806/71 (Log Sheet No. 6)

In addition, the nozzles were opened out in order that the specified steam consumption would obtain.

The results recorded by the log shew that the output obtained was 61.8% of the full duty. These results will be of value in reaching certain conclusions.

Further tests with these nozzles were suspended, and the seven Mirrlees Watson nozzles re-fitted.

OUR TEST Log Sheet No. 7. 28th April 1939)

The object of this test was to establish the maximum output of the plant with chilled water "low" at 35° F. combined with the lowest possible condenser pressure. It was desired to increase the condenser pressure whilst the plant was in operation in order to establish the "break" point.

It will be noticed that the difference between the chilled water outlet temperature and the temperature corresponding to the flash chamber vacuum is greater with chilled water temperatures at lower than specified levels.

The compressor "broke" with a compression ratio of 14.3 and recovered with a compression ratio of 13.54. It was particularly noted during the runningof this test, that the machine appeared steady and quiet and easily controlled in spite of the high ratios of compression maintained.

The outputs, of course, varied with the ratios.

OUR TEST (Log Sheet No. 8. 28th April 1939)

The object of this test was to demonstrate the maximum ratio of compression obtainable with the least possible vapour flow from the flash chamber.

The extraction pump was shut down and isolated, the water level in the flash chamber being just above the outlet pipe.

The condenser pressure maintained was that corresponding to specified conditions, i.e. 28 in. Hg.

The compressor rapidly reduced the pressure in the flash chamber, eventually stabilizing at 2.0 m.m. (= .038 lbs. abs. = 14.1° F.)

The writer is of the opinion that a still lower pressure would have been reached if the system had been as carefully jointed as no doubt it will be on board ship.

One compressor "break" was observed at a compression ratio of 25.25. This was probably due to variation in steam pressure.

OUR TEST (Log Sheet No. 9. 28th April 1939)

The object of this test was to determine output under increasing load and to determine at what load the compressor would fail.

The test commenced with chilled water temperatures and condenser pressure approximating specified conditions. The chilled water temperature was gradually increased whilst the condenser pressure was maintained as constant as possible.

Eventually an inlet water temperature of 84.5° F. was reached and the compressor had not failed, nor did it show any signs of doing so.

An output by chilled water of 3,024,000 BTU/hr. was finally reached.

OUR TEST (Log Sheet No. 10. 2nd May 1939)

As would be expected, Mirrlees Watson desired to investigate

the possibility of reverting to their own basket type sprays in view of the extra expense of the Korting nozzles.

The Korting nozzles were therefore removed and the basket sprays re-fitted. Otherwise the plant was arranged as for the immediately preceding tests.

The output obtained was 85% of that specified.

This should be compared with results recorded by Log Sheet No. 1, which shewed an output of 98.4% of full duty.

Mirrlees Watson's desire to dispense with the Korting nozzles therefore did not receive support.

OUR TEST (Log Sheet No. 11. 4th May 1939)

Before this test was carried out, contact was made with Messrs. John Brown and they were invited to send their representatives to witness an official acceptance trial.

Log Sheet No. 11, records the trial at which were present Mr. W. Harding (Cunard White Star), Mr. J. Harding (John Brown & Co.)

The plant was run for six hours, during which the output was demonstrated as well as the breakdown point obtained by raising the condenser pressures.

The two gentlemen mentioned above were given every facility for inspection and examination.

They expressed satisfaction with the performance of the plant.

OUR TEST (Log Sheet No. 12. 5th May 1939)

It was desired to show what improvement, if any, would be obtained by using the seven Carrier nozzles fitted with their exits in exactly the same position as the seven Mirrlees Watson nozzles.

The nozzles were those previously used (tests recorded on Log Sheet Nos. 4, 5 & 6) to drawing No. 5806/72 "Queen Elizabeth. Carrier Test Nozzle" and the seven nozzles were arranged as shewn on drawing No. 5806/71 "Log Sheet No. 12".

Specification conditions obtained.

The output recorded was 1,199,900 BTU/hr which is 77.3% of the full duty as against 61.8% on test recorded by Log Sheet No. 6.

After the output test was completed, a trial was run to determine at what compression ratio the compressor would fail and it was found that with a compression ratio of 8.2 the compressor "broke" and upon a gradual reduction of the ratio, the compressor picked up at a ratio of 7.86.

FLOAT CONTROL.

A test was carried out on this unit and it was observed to function correctly.

It appeared, however, to be slow in correcting the water level in the flash chamber and the drawings and arrangement will be examined with this in mind.

OBSERVATIONS

Referring to Log Sheets A, B, C & D and in particular to the Mirrlees Watson single nozzle it is pointed out that the designed diameter of the orifice of this nozzle is 16.1 m.m.

It was discovered that the shops, in error, had made the orifice 17.3 m.m. diameter.

The calculated steam consumption entered on the logs, however, are based upon an orifice diameter of 17.3 m.m.

A separate test by Mirrlees Watson should be mentioned.

It has previously been noted that Mirrlees Watson held very decided opinionn of the value of the single nozzle which they were reluctant to discard.

At a certain stage, I found they had made another single nozzle precisely similar to the first but with the correct orifice diameter, that is 16.1 m.m. I learnt that they had run a test on the 3rd May (I was not present) with this new nozzle, fitted, I understood, at a distance from the inlet to the compression cone different to previous tests.

No figures as to the results obtained were available, but Mr. McNaught told me in replies to questions that results were "pretty much the same as before".

After this, no further mention was made of the matter of single nozzle design.

During "shake down" runs on the machine, details of which do not appear on the log sheets, I noticed variations

in output which at first were difficult to account for. A number of these variations disappeared after a general tightening up of joints. Particularly I noticed an improvement after the large joint between the flash chamber and the air trunk had received attention.

It would appear therefore, that it is of some importance that as few leaks as possible exist in the vacuum system as their effect on results is perhaps greater than would ~~perhaps~~ be anticipated.

In regard to the design of nozzles for the production of vacua, I had much discussion with Mr. McNaught. It was evident that their design was almost wholly the result of trial and error. I cannot say I obtained any information of value on this point. They have a long experience behind them but had not previously handled a plant of such capacity as the one now under discussion. They spent much time and money on this contract in trying out various nozzles in an endless variety of positions in the air box but the value of these tests appeared to me to be considerably reduced if not entirely lost owing to the inaccuracy of observation and the almost total failure to record results.

Even on their routine productions, there is no co-operation between the test bed and the design department. For instance, should an ejector not perform its rated duty, the test bed foreman will open out the orifice, and increase the steam consumption without noting the amendment to the D.O. and without entering the increased steam consumption on the test certificate. This is not written as a criticism but for our own information should further work of this description be entered into with Mirrlees Watson.

The following may be of interest :-

The test bed foreman shewed me a copy of a test

certificate recording a vacuum of 0.3 in. Hg. abs. with steam at a pressure of 32 lbs./sq. in. gauge (no load and no steam consumption given).

Another showed an air pump which removed 5.8 lbs/hour/air 0.6 in. Hg. abs. with a steam pressure of 30 lbs/sq. in. gauge and consumption of 300 lbs/steam/hour.

In regard to the Korting spray nozzles, full information of various tests made is filed on "Refrig. Reports File".

On examining some of the nozzles from the flash chamber which had been in service during the trials, I found traces of cotton waste and the question of the choking of sprays may be thought one for consideration.

I have obtained one of these sprays for examination.

In order to check flash chamber temperatures against m.m. pressure given by the absolute pressure gauge, I obtained a vacuum flask (see description in Refrig. Reports File).

Although carefully fitted and proved to be air tight, I was unable to make the temperature reading given by the vacuum flask thermometer agree with those of the thermometers in the flash chamber shell or with the pressure readings of the absolute pressure gauge.

I am unable to give a reason for this failure, the sympton of which was a persistent higher reading on the flask thermometer. There was also a considerable time lag in the temperatures.

It was noticeable that under certain conditions the use of the vacuum flask affected the readings of the absolute pressure gauge which were on a common line to the flash chamber.

W.F. SCOTT.