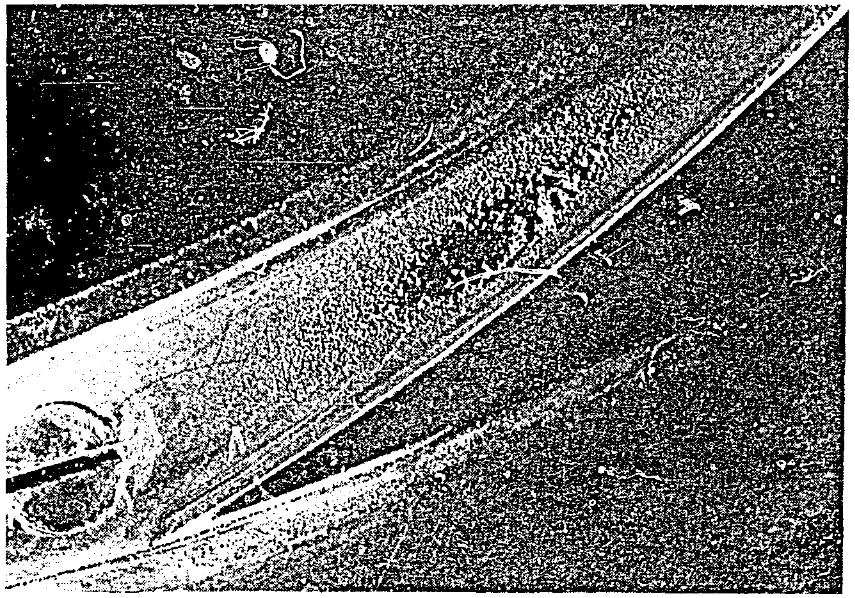
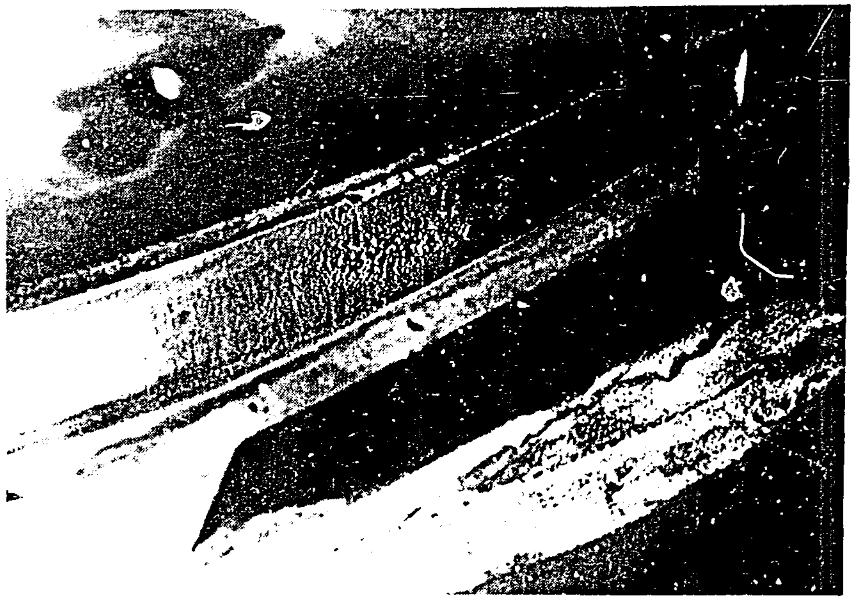


Circuit CAPHE. Bas du diffuseur. Cavitation entre les aubes

PHOTO 2

Bas du diffuseur. Cavitation côté interieur de l'aube.

PHOTO 3



Circuit CAPHE. Haut du diffuseur. Erosion de cavitation.

PHOTO 4

14 " The Effect of Pump Cavitation on the Design of the Primary Pumps for C.F.R., R.C. WORSTER, Weir Pumps, U.K.

SUMMARY

In the design appraisal of the sodium pumps for the primary circuit of the proposed 1300 MW(e) CFR it has been recognised that cavitation, its effects and its control, is the outstanding hydraulic design problem.

Careful consideration of this problem and of the possible effects of pump cavitation on the performance of other reactor systems has led to the conclusion that it is more prudent at present to specify pumps with zero cavitation at normal full speed operating conditions. Under abnormal operation it may be necessary to reduce the pumps' speed to prevent cavitation in the pumps or associated equipment.

The principal reasons for this decision were uncertainties concerning the possibility of erosion due to limited cavitation in sodium and the possibility of pump cavitation noise interfering with acoustic detection of malfunctioning of reactor components or of boiling in the reactor core.

LIMITED PUMP CAVITATION IN WATER

In conventional water pumps cavitation is acceptable if its extent is limited: there is then no loss of efficiency, little risk of unstable operation and no risk of cavitation erosion when sufficiently resistant materials of construction can be used. The noise generated by limited cavitation is usually tolerable and of a sufficiently high frequency not to excite dangerous structural resonances.

Water pumps which satisfy the above can be designed at speeds up to about

$$\omega_{ss} = \frac{\omega \sqrt{Q}}{(g \cdot NPSH)^{.75}} = 3.5$$

but they will have considerable areas of cavitation at the inlet of the first stage impeller, even at their optimum flow.

If cavitation is to be totally avoided it is not practical to design pumps to run faster than $\omega_{ss} = 2.5$, and even then zero cavitation can only be ensured over a relatively narrow range of (flow/speed) ratio.

NOISE LEVELS OF LIMITED PUMP CAVITATION IN WATER

Fig. 1 shows the sudden and substantial increase of water borne noise as the speed of a pump is increased, while keeping NPSH and throttle constant. The results are presented in a semi-dimensionless form which attempts to eliminate the effect of the changing speed during this test. The reason for the apparent variation of non-cavitating sound power as the 3rd power of shaft speed is not known - perhaps it was due to a variation of the free gas bubble content with water speed. The pump in Fig. 1 was a commercial conical flow pump of about $\omega_s = 1.6$ in a test loop with a substantial content of free air in the test water.

Another set of results on the onset of pump cavitation noise in water is given in Fig. 2 for a pump of lower specific speed ($\omega_s = 0.5$) in a test loop where the free air content is kept low in order to help flow visualisation and to permit accurate determinations of the inception of visual cavitation. In this test a rise of noise level of 10 dB corresponded to a very small cavity on the leading edge of only one blade of the impeller.

The impeller used for the tests shown in Fig. 2 was a commercial sand cast metal impeller with the blade inlet surfaces carefully smoothed by hand filing. There was a great variation between the visual cavitation inception performance of each blade: visual cavitation inception on the best blade did not take place until the NPSH had dropped to about half the NPSH at which cavitation started on the worst blade, that is near the peak of the noise curve. Loss of efficiency commences at still lower NPSH, on the falling part of that noise curve.

PUMP NOISE LEVELS IN SODIUM

We have no directly comparable measurements of noise levels on the same pump tested in water and then in sodium under comparable conditions of inlet flow distribution, of free and/or dissolved gas contents and of terminal acoustic impedences. For this reason we must assume that the first inception of pump cavitation in sodium would be accompanied by a sudden rise of noise level at least as abrupt as that shown in Fig. 2.

At the present time it is thought possible that high frequency pump noise levels, or changes of level, of this order could endanger acoustic monitoring of the reactor performance. Consequently it is safer, at this stage, to conclude that all audible cavitation should be avoided in the primary sodium pumps for CFR.

CAVITATION EROSION OF PRIMARY SODIUM PUMPS

There is only a little quantitative knowledge of the resistance of stainless steel to erosion by cavitation attack in sodium at low pump speeds and there is no information at all at the higher linear velocity needed to generate the higher heads required of the primary pumps for CFR.

It has been said that sodium is unlikely to be a lot worse than water for cavitation erosion of stainless steel. If this were indeed true, then sodium cavities of a few mm. length may not be aggressive, even on a life span of say, 30 years. However, a comprehensive and long duration test program would be needed to proove that limited sodium cavitation would not be aggressive. Even then, there must be doubt about the validity of rig tests scaled to the working conditions of the very large primary sodium pumps needed for CFR. For instance, even if we knew the effects of speed and pressure/time relationships, it would still be extremely difficult to ensure the proper representation of the gas constant of the pumped sodium that would be encountered in the reactor environment.

This situation has further strengthened the opinion that the primary sodium pumps in CFR should be designed for zero cavitation at their normal running conditions.

NUCLEATION IN THE SODIUM IN CFR AND REPRESENTATION IN WATER TEST RIGS

It has been suggested that a delay of the onset of cavitation in a large clean sodium pump might arise due to the very low solubility of gas in sodium at the temperature at the pump inlet and to the likelihood of the sodium becoming degassed due to its continuous recirculation.

However, the gas solubility/temperature characteristic for sodium differs from that of water and it is more likely that gas will be absorbed at the high temperature free surface and then be released by the turbulent flow and temperature drop through the IHX's, maintaining a continuous population of small bubbles in the sodium at the pump intake: this could easily be sufficient to reduce cavitation inception lag to a negligible magnitude.

Consequently, it is essential that water test rigs for models or prototype pumps should have an adequate continuous supply of nucleii to ensure similar negligible cavitation inception lag.

POTENTIAL SOURCES OF CAVITATION IN PRIMARY REACTOR PUMPS

There are at least five different sources of cavitation in the primary sodium pumps for pool reactors:

(1) Impeller Blade Cavitation

Methods of calculating the pressure drop at the leading edges of the impeller blade are available today for simplified flow boundaries, but it is not possible to assess what happens in the boundary layer flows on stationary casings and inlet guide vanes, rotating shrouds and hubs, and especially where blades and shrouds intersect and substantial fillets are desirable for strength and manufacturing reasons.

(2) Impeller Seal Cavitation

The flow through rotating neck ring seals used to minimise internal leakage losses and to minimise the disturbance to the flow entering the impeller near the outer shroud is the next most important source of pump cavitation.

There is an uncertainty concerning the cavitation numbers that are needed for different designs of seal if cavitation noise is to be avoided.

Visible cavitation in the turbulent jet emerging from a neck ring seal in a pump appears at a cavitation number of about 1.0, but it has been suggested that 3.0 may be needed to suppress seal cavitation completely. This cavitation number is the local downstream mean static pressure (above vapour pressure) divided by the efflux jet dynamic pressure.

An experimental verification of this has not yet been achieved in a pump because special test arrangements are needed to distinguish seal cavitation noise from blade cavitation noise.

(3) Diffuser Cavitation

The unsteady flow from the impeller can produce fluctuating pressures and cavitation at the diffuser inlets. This may be unavoidable at severely off-design duties but it should not present a serious problem if sufficient settling lengths are allowed between the impeller outlet and diffuser inlet. Such gaps increase the overall size of the pump but they are desirable to minimise low frequency blade rate noise generation.

(4) Bearing Cavitation

The hydrostatic pump bearing is another possible source of pump cavitation noise, but there is no experimental data on critical cavitation numbers or noise levels of representative bearings.

(5) Shut-off Valve Cavitation

If the pump isolating valves are on the discharge side of the pumps there will be no problem of cavitation noise when they are fully open. Cavitation may be unavoidable during some starting or stopping transients but it would be important to ensure freedom from clearance leakage cavitation in the closed position, when one pump is valved-off and the others are running fast. Special water model tests would settle the hydrodynamic problems but thermal and pressure distortion problems are also involved.

CAVITATION SCALING EFFECTS

There is no alternative to doing the majority of the primary pump hydraulic development work with reduced scale water models so that scale effects between model test cavitation performance and full scale pump performance in the reactor will arise due to:

(a) Inaccuracy of reproduction of impeller geometry (including roughness and crevices).

(b) Differences of liquid nucleation and cavitation growth mechanisms.

(c) Differences in inlet flow distribution.

(d) Differences of acoustic terminal impedances.

Programs are being prepared to identify practical margins of cavitation performance that will make reasonable allowances for the above scaling factors.

ACKNOWLEDGEMENT

This report is intended to represent the joint opinion of The Nuclear Power Company (Risley) Ltd., The GEC Reactor Equipment Ltd. and of Weir Pumps Ltd.

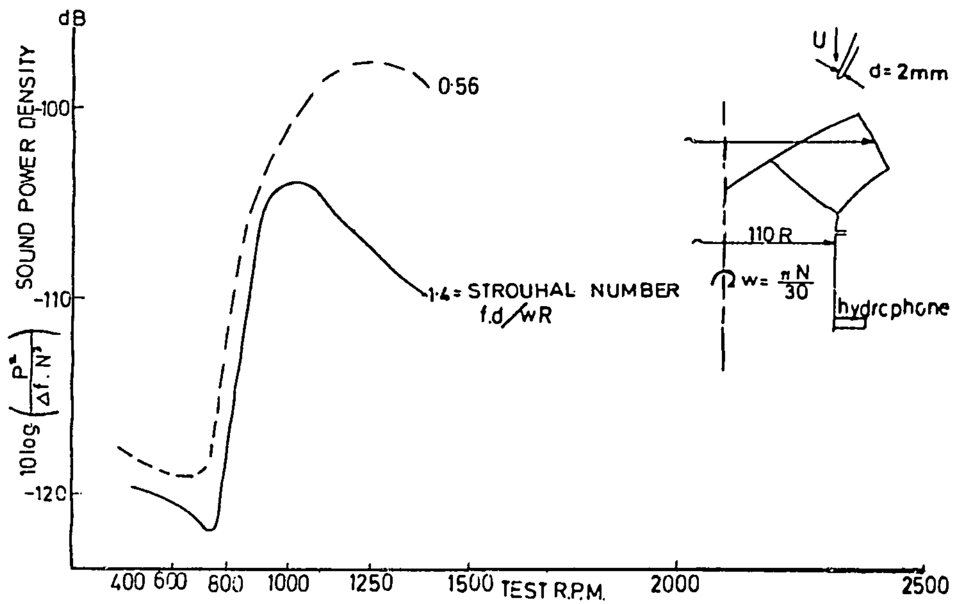


FIG1 INCEPTION OF CAVITATION NOISE IN PUMP AS SPEED IS INCREASED AT CONSTANT THROTTLE AND NPSH. P = THIRD OCTAVE SOUND PRESSURE (PASCAL), f = FREQUENCY, Δf = FREQUENCY BAND WIDTH (Hz) N = RPM.

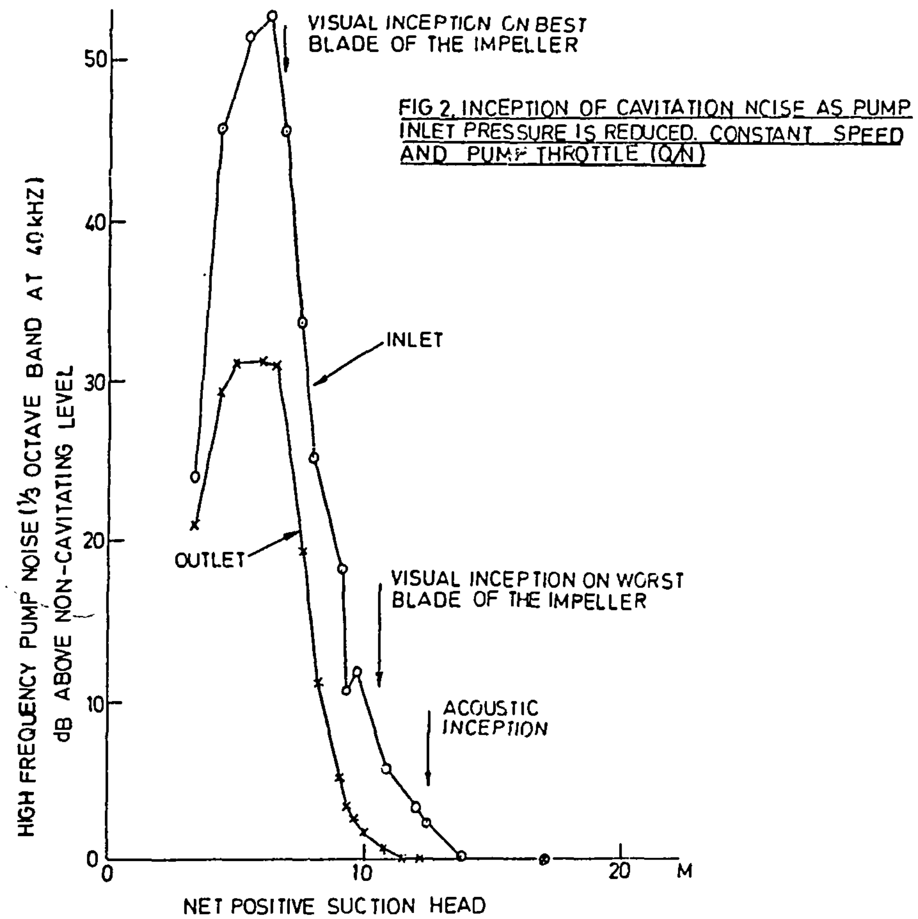


FIG 2. INCEPTION OF CAVITATION NOISE AS PUMP INLET PRESSURE IS REDUCED. CONSTANT SPEED AND PUMP THROTTLE (Q/N)

15 " Cavitation Work Conducted at Risley Engineering and Materials Laboratories, A.E. COLLINSON, U.K.A.E.A., U.K.

Cavitation in Reactor Components

It is important to minimise cavitation in PFR for two reasons: firstly to reduce the risk of damage from erosion and secondly to reduce the background noise when using acoustic diagnostic techniques for core protection. It is therefore necessary to determine the inception of cavitation noise for reactor components rather than the fall in hydraulic performance of common engineering usage, such as for a pump. In PFR most attention has been paid to two types of component; pressure dropping devices, including fuel sub-assemblies and the pump.

The investigation of cavitation in pressure droppers is described by Collinson (1) in a paper presented to this meeting. The method of acoustic detection used, for experiments in both water and sodium, is based on the count rate arising from the collapse of individual vapour bubbles. It was assumed that, in the absence of cavitation noise, erosion would not occur, and little effort has been devoted to the investigation of damage produced by cavitation.

For the PFR pump, the specification agreed with the manufacturer was that at the design point there should be no visible evidence of bubble formation on the impeller blades. The use of visual techniques is obviously not practicable in sodium and the alternative method of using acoustic listening methods has been investigated. In the earlier experiments, using water, results were confusing but by minimising spurious noise and attenuation effects, and by having a panoramic viewing system, it has been found that similar results could be obtained using acoustic and visual methods. This is illustrated in Figure 1 which shows the relation between noise (at 40kHz) and inlet pressure for one particular pump. An interesting feature of this curve is the steep rise in noise once cavitation starts. Thus if damage from cavitation erosion is important and if this noise curve is typical there may not be a clear criterion for its avoidance after the inception of cavitation. The degree of cavitation to accept from a sodium coolant pump is presently under review. Additional experiments have been carried out to locate cavitation sources on pumps using the triangulation techniques developed for stress wave emission measurents by Bentley et al(2). The first measurements were made on a stationary centrifugal pump with simulated cavitation sources and showed that despite the complexity of the transmission paths the sources could be uniquely located in the three dimensional structure. Further measurements have been made on an operating pump system. This readily distinguished pump from valve noise. Two sources were identified in the pump casing, one indicating cavitation over the impeller blades and the second stationary, indicating a leak from high to low pressure. The investigation is continuing with the development of specialised equipment for the source location of intense cavitation.

Detection of Gas Bubbles

Cavitation behaviour can be influenced by the numbers of free background gas bubbles in the system. It is necessary to define both size spectrum and total volume fraction of bubbles in order to characterise the background gas level. An instrument for the detection of entrained gas bubbles has been developed at REML relying on the Doppler effect on high frequency sound scattered by bubbles in a flowing liquid. The device is outlined in Figs 2 and 3.

References

1. 'The Onset of Cavitation in Pressure Dropping Devices in Water and Sodium' by A E Collinson

2. 'Instrumentation for Acoustic Emission' by P G Bentley et al TRG Report 2482(R) United Kingdom Atomic Energy Authority, Risley, Warrington, Cheshire.