IAHR AIRH

SYMPOSIUM 1970
STOCKHOLM

SURGE AND WATER HAMMER PROBLEMS IN THE COOLING WATER SYSTEM OF LARGE THERMAL POWER PLANTS

Bengt Jansa, consulting engineer Vattenbyggnadsbyrån Gothenburg, Sweden

SUMMARY:

Design criteria for calculating cooling water (C.W.) flow through condensers are stated in respect of level-conditions, surges, and vacuum risks. The influence of rotating parts in the axial flow pumps at the moment of power failure is discussed and the method of calculating C.W. flow through a system of tunnels and shafts including the effect of pump characteristics is described. The criteria have been used for design work at three new Swedish power stations.

RESUME:

Problemes d´oscillations de pression et de coups de bélier dans le circuit de refroidissement par eau d´une usine thermique de grande puissance

Les critéres servant au calcul de la circulation de l´eau de refroidissement à travers des condensateurs de centrales thermiques sont donnés en tenant compte des niveaux, des oscillations de pression et des risques de vide. L´action de parties rotatives de la pompe lors d´une coupure brutale de courant est discutée et une méthode de calcul de la circulation de l´eau de refroidissement à travers un système de tunnels et d´arbres est décrite. La méthode donne également de résultat de caractéristiques techniques de la pompe. Cette méthode de calcul a eté utilisée pour l´étude de trois nouvelles centrales thermiques suédoises.

Introduction

Starting and stopping as well as any changes in the great cooling water (C.W.) flow through a thermal power station cause pressure oscillations in the C.W. system. At the inlet side of the power station´s C.W. system these oscillations mean surges in screen and pump chambers which, if uncontrolled, can cause flooding and damage to the machinery.

Within the condenser the pressure oscillations can cause water hammers and at the moment of starting unexpectedly high pressures. When stopping, the oscillations can result in undesirable low pressures with a risk of vacuum and water hammers.

On the C.W. discharge side the oscillations mean pressure, vibrations or surges. Due to the technical shape of the discharge tunnel(s) or pipe(s), and their different parts, the surges and pressure pendulations can damage the machinery and lead to flooding.

During recent years these problems have been closely observed at many power stations all over the world and a great deal of work has been done to find solutions and to master the problems. When starting the C.W. flow the pressure variations can be reduced by smooth starting or efficient regulation. Due to the technical lay-out and siting level of the power station, many C.W. pumps are of the axial flow type operating at high specific speeds and cannot be regulated at the moment of starting. The pumps are generally connected to short circuited electric motors and have a very rapid starting process, which in the case of non-evacuated condensers, can cause vibrations and pressure shocks. These vibrations are normally under control as the pumps are started one by one to reduce the start effect. However, consideration had to be given to the possibility that in the case of power failure, all pumps may stop suddenly without warning. These stops give maximum pressure variation of the same magnitude as if all C.W. pumps were started simultanously.

During the design stage the pressure vibrations and surges can be reduced to an acceptable level. In the following pages it will be shown how these questions have been solved at three new Swedish power plants, namely:

Aros Kraft	thermal oil fired power station, stage 2; 280 MW el.
Karlshamn	thermal oil fired power station, stages 1 to 3; each 320 MW el.
Oskarshamn	nuclear power station, stages 1 and 2; 400 + 600 MW el.

Technical lay-out and flow characteristics

Each of the three stations is located close to a shore where cooling water is led to the pumpsumps (chambers) through intakes, tunnels and screening plants. Vertical mounted axial or semiaxial flow pumps draw the water through condensers working as evacuated siphons. The cooling water discharge passes through surge shaft(s) to the recipient, the Baltic Sea and Lake Malaren. The surge shaft at Aros Kraft is connected to the intake system with an overflow and at Oskarshamn with a regulated recirculation system mainly for preheating the cooling water during the winter period. Some schematic lay-outs of the cooling water systems are shown in Fig. 1, and a section of one of the cooling water pumps and condensers at Oskarshamn is shown in Fig. 2.

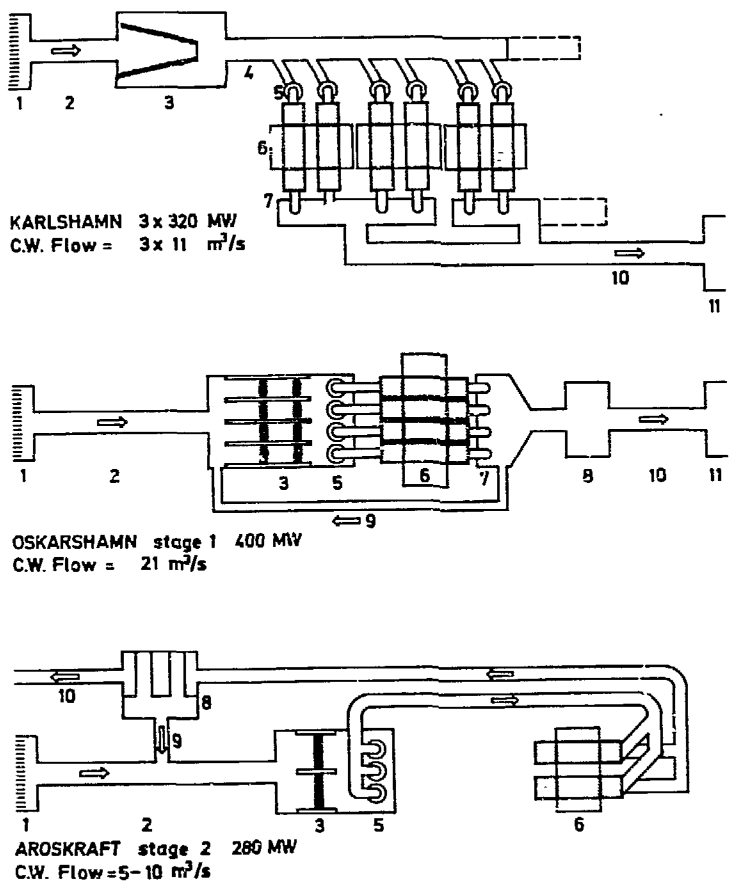

Fig. 1

Schematic lay-outs of the cooling water systems at three new Swedish power stations.

LEGEND

1. INTAKE AND RACK
2. INTAKETUNNEL
3. SCREEN
4. DISTRIBUTION TUNNEL
5. C.W. PUMPS
6. CONDENSER
7. CONDENSER OUTLET
8. SURGE SHAFT
9. RECIRCULATION OWERFLOW
10. WARM WATER DISCHARGE TUNNEL
11. OUTLET

In continuous flow the characteristic energy curve follows the friction losses through pipes and condenser as may be seen in Fig. 2. At many stations, due to the level of the turbine, the absolute pressure is very low at the outlet side of the condensers. This means that when starting and stopping the C.W. flow the surges in the pump-chamber and surge shafts can still further reduce the absolute pressure until vacuum is formed with a possibility of water hammers, damaged tubes and end-plates of the condenser.

Calculation of surges

The surge pendulation and the variations of the C.W. flow are calculated as a non-stationary motion-problem, in which acceleration phenomena cannot be neglected, but phenomena of compression can. The calculations are carried out for continuous flow throughout the whole C.W. system. For all parts of tunnels or pipes and their surge shafts three equations are given and for a system of N surge shafts a total of 2N+1

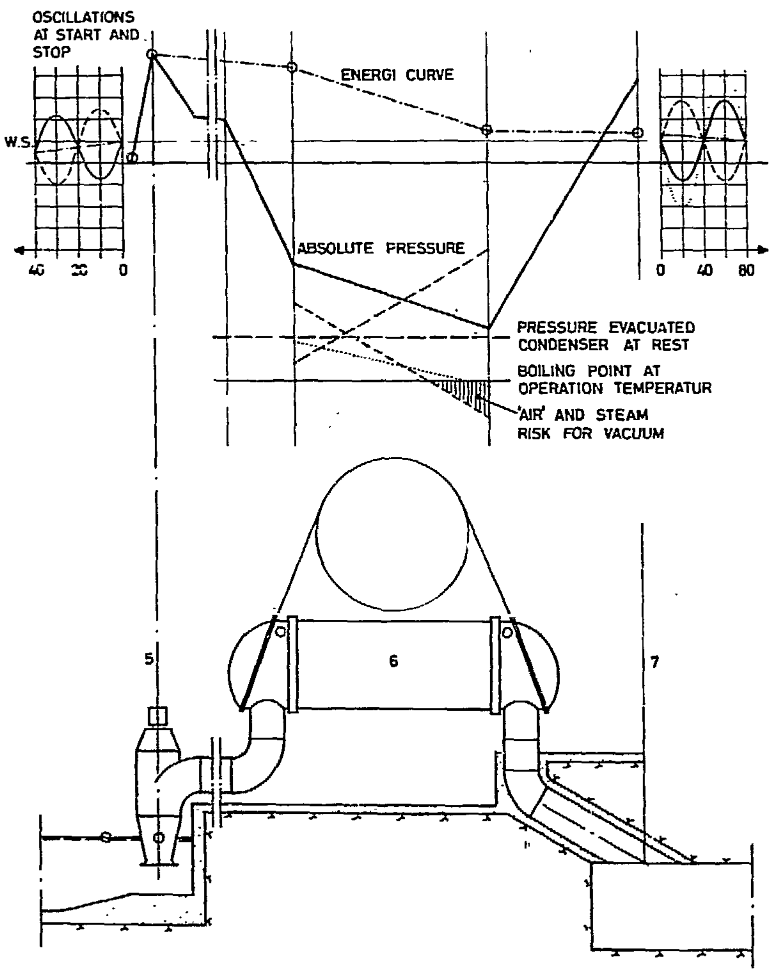

Fig. 2

Crossection through one of the cooling water pumps and condensers at Oskarshamn power station.

Each pump and condenser have a capacity of a C.W. flow of 5-6 m^3/s.

J 1

equations of the following type is provided, the symbols corresponding to those in Fig. 3

$$\begin{cases} (z_{n-1} - z_n) - K_n \cdot Q_n^2 + C_n\left(1 - \frac{Q_n}{D_n}\right) = \frac{l_n}{a_n \cdot g} \cdot \frac{dQ_n}{dt} & (1) \\ (z_n - z_{n+1}) + K_{n+1} \cdot Q_{n+1}^2 = \frac{l_{n+1}}{a_{n+1} \cdot g} \cdot \frac{dQ_{n+1}}{dt} & (2) \\ F_n \cdot \frac{dz_n}{dt} = Q_n - Q_{n+1} & (3) \end{cases}$$

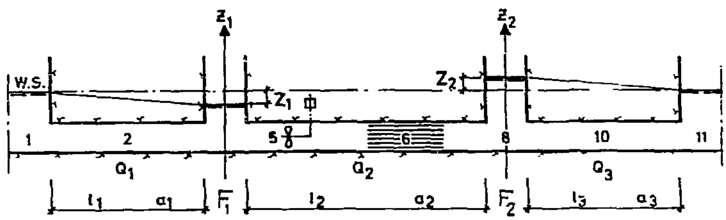

Fig. 3

Schematic cross-section through C.W. system. Numbers within the figure correspond with fig. 1.

The term $C_n(1 - \frac{Q_n}{D_n})$ takes into consideration the effect of a pump placed within a pipe (l_n) and with a straight characteristic line over the normal working range. The equations are transformed into difference equations for step by step integration, by hand or by a digital computer programme.

Input data are lengths (l, m), areas (a, m^2), and friction coefficients (K) given as a 1 m^3/s-value of tunnels or pipes hydraulic losses. Pipes and tunnels with varying areas between two shafts are replaced by equivalent area (or length). Areas of shafts (F m^2) and flow in pipes and tunnels (Q m^3/s) are used.

Output gives flows (Q-values) in tunnels and pipes, and level variations (z-values) in surge shafts. A digital computer calculation for the C.W. system of Oskarshamn nuclear station is shown in diagrams, Fig. 4.

Sometimes it is necessary to correct the surge amplitudes with respect to the effect of the moment of inertia of the rotating parts in pumps and rotors. Most pump manufacturers give on request the pump characteristics during sudden power failure and reversed flow. These Q/H-curves must be determined experimentally in the workshop.

The tangent-gradient for the pumps Q/H-curve and for the C.W. flow curve at time t = 0 after a sudden power failure are compared in the following two equations: Symbols from Fig. 3.

$$T_{o-n} = \left(\frac{\pi}{30}\right)^2 \cdot \frac{J}{N} \cdot \int_o^n n\,dn \qquad \text{(seconds)} \qquad (4)$$

$$T_{\substack{o-Q \\ \text{C.W.} \\ \text{flow}}} = - \frac{l_2}{a_2 \cdot g\,(Z_1 - Z_2 - K_2 \cdot Q_2^2)} \cdot \int_o^{Q_n} dQ \qquad \text{(seconds)} \qquad (5)$$

The equations normally give the result, namely that following a power failure the C.W. flow through the pump decreases more rapidly than the corresponding C.W. flow in the system. During a short period following power failure the pump and rotor, due to rotating energy, give a higher Q-value for the flow through the pump than that given by kinetic energy of the flow alone. The surges must be corrected in respect of this extra C.W. flow. After a time T_{o-n} the pump and rotor stops

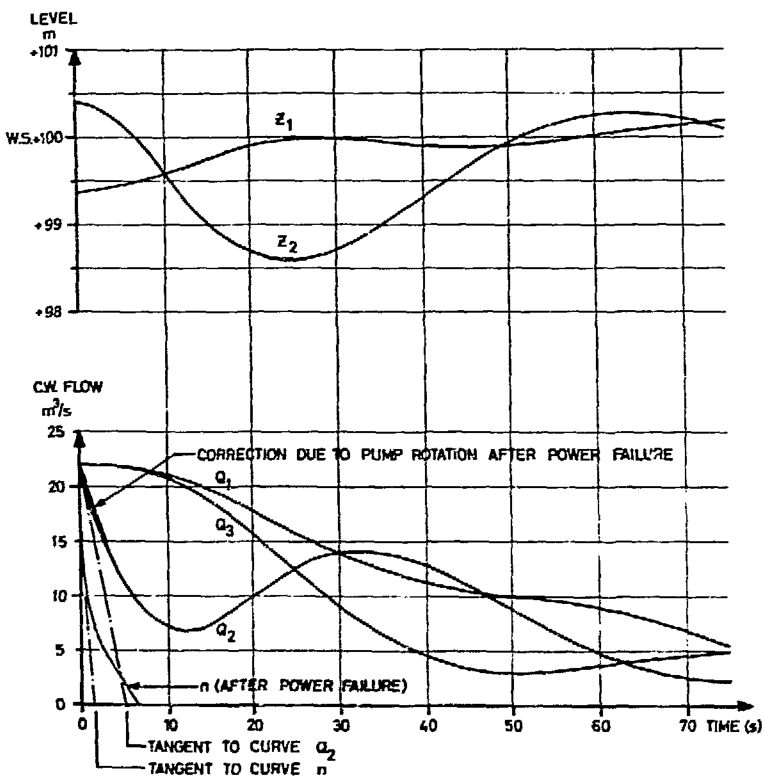

Fig. 4

Surges in pump chamber (z_1) and surge shaft (z_2) and C.W. flows in tunnels (Q_1 Q_3) and condenser (Q_2) system following power failure. Tangent to curve at time t = 0.

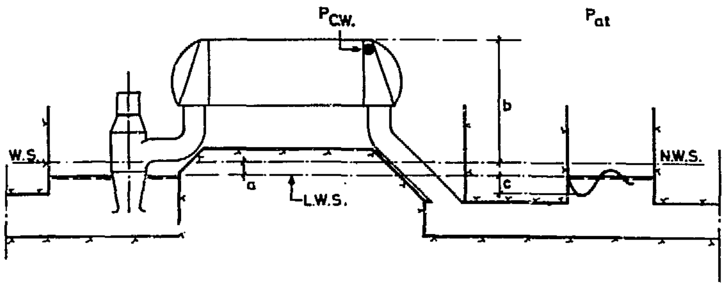

Fig. 5

Critical distances and pressures for the location of a condenser operating as a siphon.

and now the pump acts as a partly open gate which gives the pipe in question an extra hydraulic loss. Correction to the extra C.W. flow and to the extra hydraulic loss is taken as shown in Fig. 4.

Design criterias

Areas F of the surge shaft and the top level of the condenser must be calculated, consideration being given to the factors presented in the previous section. Vacuum problems inside the condensers should be avoided. In order to meet these demands, the following formula can be stated. Measured from the reference level of the station (normal water surface) and with symbols taken from Fig. 5:

$$a + b + c + p_{cw} = p_{at} - s \tag{6}$$

where a, b, c are measured in (m) from the sea´s normal water surface (N.W.S.).

p_{cw} is the boiling pressure of C.W. (m water) within condenser´s outlet (temp. $10^{o}C - 25^{o}C$).

p_{at} is the atmospheric pressure (m water)

S is safety margin, 0.25 m.

If the lay-out and level conditions in this respect imply a risk of vacuum forming in the condenser, the formula can be satisfied by

1. reducing the maximum surge (c) with the aid of a larger surger shaft
2. reducing (a) and (b) with an overflow weir at the outlet
3. by placing an automatic air valve on the top of condensers outlet end which opens at condenser-pressures lower than (s) m water.

Notation

Symbol	Units	Description
l_n	m	Length of any uniform section of pipe or tunnel
A_n	m^2	Cross-sectional area of pipe or tunnel
F_n	m^2	Cross-sectional area of surge shaft
Q_n	m^3/s	Flow in pipe or tunnel
z_n	m	Height of water surface in surge shaft measured positive above W.S. in the sea
Z_n	m	Height of water surface in surge shaft at continuous flow
g	m/s^2	Acceleration of gravity
K_n	-	Friction factor for pipe or tunnel
C_n	(m)	Pump characteristic line value Q = 0
D_n	(m^3/s)	" " " " H = 0
t	s	Time
n	rpm	Pump and rotor rotation speed
J	$kgms^2$	Moment of inertia after pump axle $M = J\frac{dw}{dt} = \frac{N}{w}$
N	kgm/s	$\frac{g \cdot Q \cdot H}{\eta}$ effect