POLSKA AKADEMIA NAUK
INSTYTUT MASZYN PRZEPŁYWOWYCH

PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH

TRANSACTIONS
OF THE INSTITUTE OF FLUID-FLOW MACHINERY

70-72

WARSZAWA–POZNAŃ 1976
PAŃSTWOWE WYDAWNICTWO NAUKOWE

PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH

poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

*

THE TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

REDAKCJA – EDITORIAL OFFICE
Instytut Maszyn Przepływowych PAN
ul. Gen. Józefa Fiszera 14, 80-952 Gdańsk, skr. pocztowa 621, tel. 41-12-71

Printed in Poland

PAŃSTWOWE WYDAWNICTWO NAUKOWE – ODDZIAŁ W POZNANIU

Wydanie I. Nakład 630+90 egz. Ark. wyd. 63,25 Ark. druk. 49,25 Papier druk. sat. kl. V. 65 g., 70×100. Oddano do składania 4 VII 1975 r. Podpisano do druku w czerwcu 1976 r. Druk ukończono w czerwcu 1976 r. Zam. 528/118. H-16/245.
Cena zł 190,–

DRUKARNIA UNIWERSYTETU IM. ADAMA MICKIEWICZA W POZNANIU

III KONFERENCJA NAUKOWA

na temat

TURBINY PAROWE WIELKIEJ MOCY

Gdańsk, 24 - 27 września 1974 r.

*

IIIrd SCIENTIFIC CONFERENCE

on

STEAM TURBINES OF GREAT OUTPUT

Gdańsk, September 24 - 27, 1974

*

III НАУЧНАЯ КОНФЕРЕНЦИЯ

на тему

ПАРОВЫЕ ТУРБИНЫ БОЛЬШОЙ МОЩНОСТИ

Гданьск, 24 - 27 сентября 1974 г.

PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH
1976 Zeszyt 70 - 72

KURT G. REINHARD, GIOVANNI P. SCHATZMANN

Switzerland*

Turbine Water Damage Prevention

Introduction

A few years ago in the United States the number of instances of damage to turbines caused by induction of water or cold steam has sharply increased. This has initiated intensive research on preventative measures by both owners and manufacturers. In this connection we would like to refer to the papers by J. H. Moore [1] and J. D. Dickinson – D. E. McKindley [2]. The latter was presented at the 1970 APC and suggested that a committee be formed to investigate measures for prevention of such damage in the future.

An American statistic on causes of damage resulting from water induction into turbines revealed that in a six years period 25 incidents caused 23 735 outage hours. 70.4% of the outages were caused by water induction through extraction lines. Assuming the same damage rate, the probability of a new machine being damaged during the first five years of operation is about 35%. Because of the extreme importance of this subject and especially since we are convinced that our experience can contribute to increasing operational safety and availability, a few of the more important points will be discussed in the following text.

Following two incidents of damage due to water and cold steam induction in 1957-58 we revised our safety philosophy and have maintained it till now. Since then our turbines have been free from such damage.

In attacking the problem of water induction into the turbine we concentrated primarily on eliminating the causes rather than trying to detect back flowing water in time through extensive and complicated instrumentation.

A very important source of danger was eliminated by principly placing the feedheaters with exception of the deaerator under the turbine. A short time ago an American utility accepted in six instances our proposal for such an arrangement.

In the following text we will briefly reconstruct the two previously mentioned incidents as a basis for a closer look at the design of the powered check valves, our safety philosophy with reference to induction of water and steam through extraction lines and finally the location and layout of drains.

---

* Brown, Boveri and Company, Ltd., Baden.

Turbine damages resulting from induced water and cold steam

The first incident involved the 120 MW reheat machine Amer IV in Holland on October 22, 1957 at 00.45 a. m. After a three hour outage to replace commutator brushes (this is carried out during operation today) the turbine tripped out soon after being run up to synchronous speed.

The following is a reconstruction of events.

During the stillstand (barring operation) the LP bypass was in operation with a reheat pressure of about 150 psig. Feedheater 7 continued to function because the steam pressure held the flaps in the extraction line open even though a closing force was applied. The condensate which formed flowed through the drains to the lower feedheaters and finally to the condenser. During the subsequent start the extraction line flaps opened automatically, powered by the safety oil pressure. This opened the passages between the feedheaters and the turbine permitting a free backflow of steam into the IP turbine which was under vacuum. The relatively large amount of steam released from feedheater 6 entered the hot (750° F) center section of the IP shell and cooled it unsymmetrically. The resulting shell distortion caused the blades to rub, removing up to 18 from the tips of blades in the IP as well as the HP. The plant returned to operation four weeks later.

During the original planned outage the operating personnel had forgotten to close the steam side shut off valve to feedheater 7. If free swinging powered check valves (see section "Powered Check Valves") instead of flaps (powered opening and closing) had been used in the extraction lines, this human error would not have resulted in a damaged turbine.

The second incident was very similar to the first. It occurred a few months later on January 18, 1958, to the 65 MW reheat machine Merxem in Belgium.

Powered check valves

After these two incidents it was decided among other things to develop a powered check valve of our own, without glands, as those commercially available were not satisfactory mainly because of jamming in the glands.

A. General

The purpose of the powered check valves is to prevent a back flow of water or steam into the turbine. A reverse flow closes them automatically and various criteria initiate a powered closing: e.g. loss of pressure in the safety oil system or a high condensate level in a corresponding feedheater. They are installed in extraction lines to feedheaters and heat exchangers as well as in the cold reheat lines of reheat turbines with bypass etc. A light, a medium and a heavy series have been designed in order to most economically adapt to various steam conditions. The heavy series is suitable up to 950 psig and 930° F. The maximum steam velocity at the seat is chosen to give a pressure drop less than 1 %. The seat diameter is smaller than the nominal pipe size. Size selection is based on a comparison between the price difference for the next larger size and the capitalized power loss reduction.

B. Design and operation

Compressed air rather than oil is the normal operating medium for servomotor *20* (Fig. 1).

When pressurized, piston *24* moves upward until spindle *15* stops against bushing *13*. This is formed as a back seat thus preventing spindle leakage. In this position the flap *3* is free to move under the influence of the steam flow. A closing impulse to pilot valve *40* relieves the pressure under piston *24* causing springs *29* and *30* to close the flap *3*.

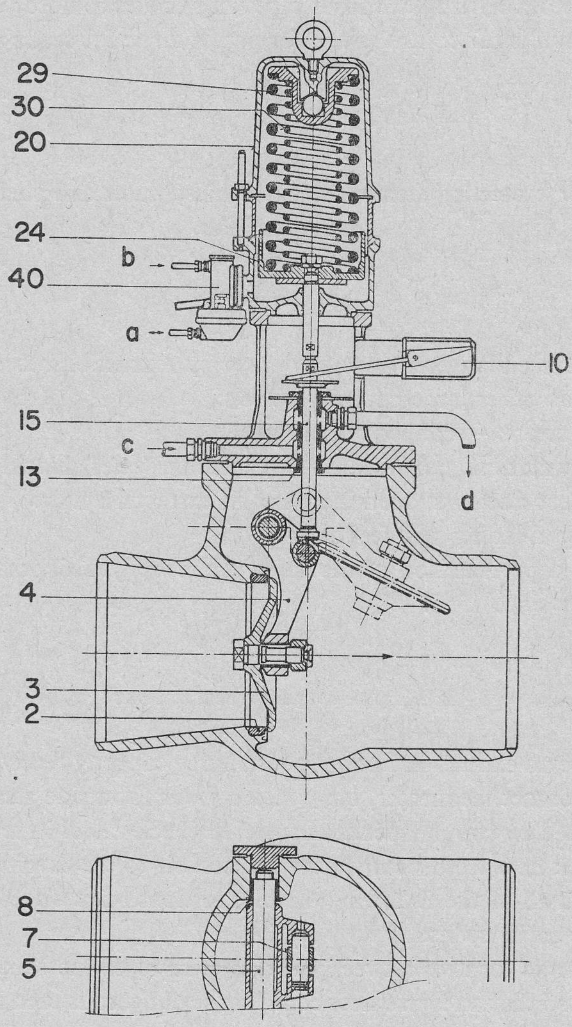

Fig. 1. Sectional drawing of a powered check valve

The spring closing force is relatively small so that a pressure difference of 7 - 15 psi across the valve (in normal flow direction) will force it open.

A functional check can be made with either the lever on the pilot valve or via the safety system. The stroke of the servomotor is indicated locally with a pointer and scale and remotely via limit switch *10*.

The number of points on the drive subject to relative movement have been reduced to a minimum. Spindle *15*, bushing *13*, roller *7*, bearing bushing *8*, seat *2* and shaft *5* are made of surface hardened stainless steel. Flap *3* is mounted with clearance on lever *4* so that sealing is insured even with a slightly deformed housing. The center of gravity of flap *3* is designed to provide an aligning component during closing. This insures that the flap is aligned parallel to the seat at the moment of closing.

Flap *3* is made accessible by removing servomotor *20* and cover *12*. The check valves are always welded into a horizontal run of pipe with the servomotor positioned vertically upwards. Connection *a* is for control air, *b* for power air, *c* for sealing steam an *d* for leakage steam.

Safety philosophy for protecting steam turbines against water and steam induction through extraction lines

A. Purpose

Steam turbines are endangered in many ways by extractions to surface and contact feedheaters as well as other large capacity vessels:

- Induction of steam – danger of overspeed.
- Induction of water and cold steam – quenching, water slugging.
- Excessive thrust due to sudden increases in extraction flow.
- Danger of overloading the feedheater.

The following is a presentation of the safety philosophy which has kept our turbines free of such damage since 1958.

B. Multiple cylinder reheat turbines

In all cases where an extraction line supplies a large capacity receiver (variable pressure heat accumulater, contact feedheater, large steam system, outside steam system), the turbine must be protected by two independent powered check valves in series. This is required because a direct back flow from a large energy reservoir to the turbine can occur. Extraction lines which fulfil all of the following three conditions must also be provided with two powered check valves in series:

- The extraction is located between two blade rows of the same cylinder in a high temperature region, so that a reverse flow could cause dangerous thermal shocks and in the case of a load rejection, dangerous overspeed.
- An isolating valve in the main steam path (e.g. intercept valves) is located between this extraction and a higher pressure one (not only the next higher). It may be that several neighbouring extractions require two check valves.
- The condensate from the next higher heater is drained to this heater.

Low capacity vessels, e.g. surface feedheaters, whose highest points lie under the turbine axis are provided with a single protection. Each extraction line to surface feedheaters with a maximum operating pressure over 25 psig is provided with one powered check valve.

– A safety device which is operated by a level monitor must be placed higher than the monitor itself. If two safety devices in series are operated by the same monitor, at least one of them must satisfy the above requirement.

– The check valves should be easily accessible for checking.

A non-powered check valve combined with a power d alve (e.g. reducing valve) are equivalent to one powered check valve. However, the closing signal which would normally go to the powered check valve must in this case close the powered valve. Motor operated valves should have a closing time less than one minute!

Only one powered check valve or an equivalent solution is provided in an extraction from the cold reheat to a surface heater or to a large vessel.

Extractions with a maximum operating pressure less than 25 psig are protected with one non-powered check valve. These should be placed as close as possible to the turbine to increase the safety against overspeed.

The check valves required for the lowest LP extractions of large plants are so big that a reasonable design is difficult to realise. They may be omitted when the following conditions are fulfilled:

– When a drain pump fails, an alarm is actuated and a level operated valve opens a direct drain to the condenser.

– If the level continues to rise a high level alarm is given and then an independent level monitor opens the vacuum breaking valve. The turbine will be unloaded via the vacuum limiter and finally tripped via the vacuum trip. The signal to the vacuum breaking valve is removed only after the level has returned to normal and the unit is shut down.

Extractions to heaters with adequately dimensioned direct drains to the condenser (no additional restrictions such as drain coolers or isolating valves) do not require isolating or safety devices.

Locating the check valves

A check valve is installed as close as possible to the turbine to increase the safety against overspeed, by keeping the stored steam volume at a minimum. It must be located upstream of the isolating valve. When there are two check valves in series only one must fulfil the above condition.

In plants with multiple parallel feedheaters the powered check valves should bo located in the common steam line near to the turbine. This is also valid when two check valves in series are requierd. If desired for planning reasons the second common check valve can be replaced by one check valve in each string.

Control of the valves or check valves

As can be seen in Fig. 2, the check valves are pneumatically operated. This simplifies planning as there is no oil leakage. They are operated by feedheater level monitors 441, 443 - 445. The impulse from the level monitor is led to a 3-way pneumatic valve 531 - 533, 535 - 538 located on the pilot valve of the check valve 501 - 506.

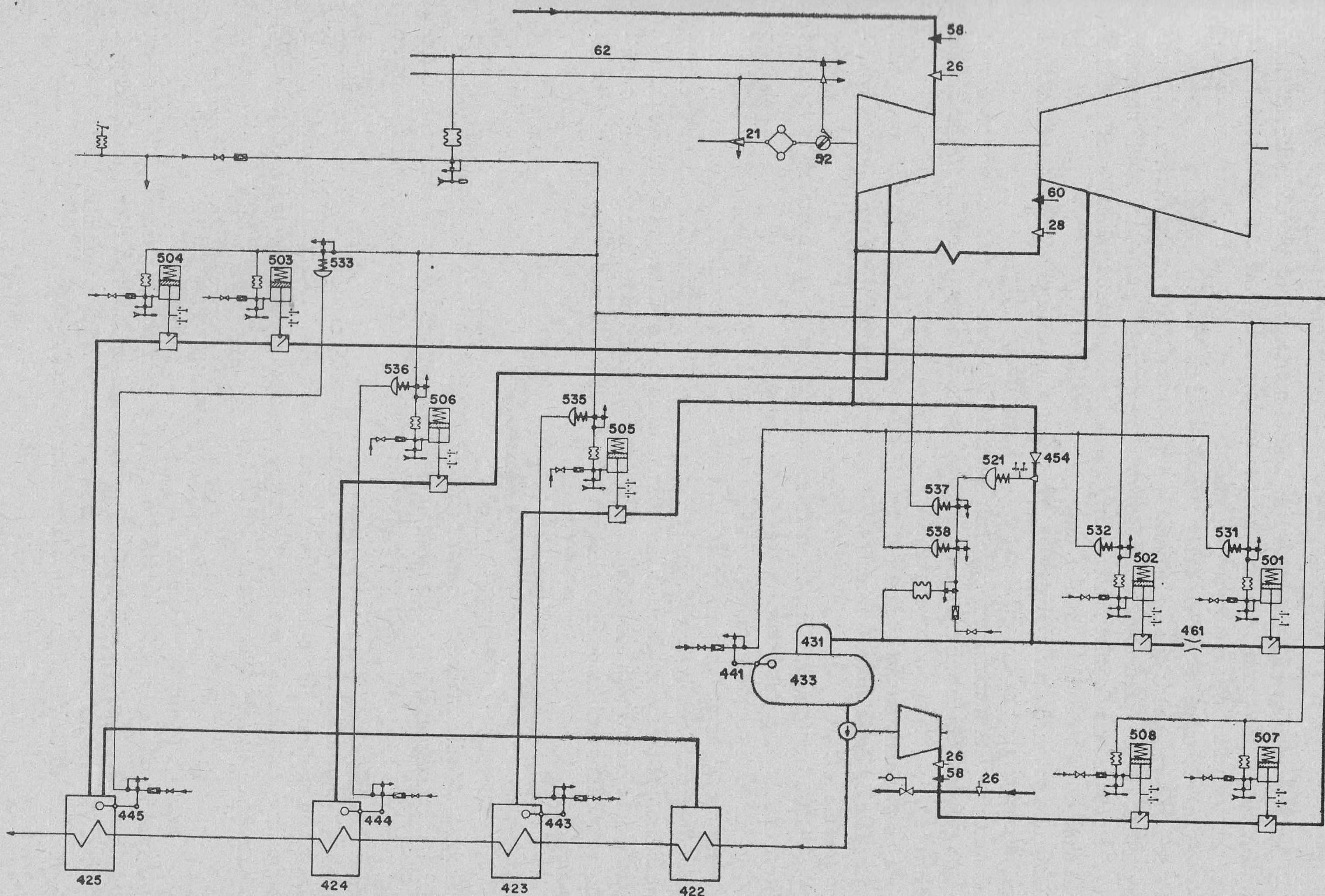

Fig. 2. Standard diagram of a feedheating plant with protection devices against reverse flow

One 3-way valve per check valve is provided. One valve is sufficient for a maximum of two check valves if these are operated by the same level monitor and are placed next to each other, 533, 503, 504. Two check valves which are wide apart 501, 502 are each provided with a valve 531, 532.

The check valves or valves in an extraction line receive a closing signal if the turbine safety oil system is relieved or if the level monitor of the corresponding feedheater of vessel is activated.

A reducing valve 521 between two extractions is operated by the safety oil system as well as the level monitors 441, 443 of the vessels supplied by these extractions.

Safety devices on HP feedheaters

An increase in drain flow causes the level controller to increase the opening of the drain valve to the next lower heater. When this valve is wide open the emergency drain valve to the condenser is opened; simultaneously alarm is given in the control room via a limit switch on the emergency drain valve. When the cause of increasing level is tube leakage the amount of water to be removed can be great; the level will continue to rise and the level monitor will close the powered check value in the extraction. The stroke limits of the check valve servomotor are indicated in the control room. The cascading drain from the next higher heater can also be shut off simultaneously. If the level still increases the electric level monitor switches the feedheater over to bypass operation (feedwater) and gives alarm in the control room.

Safety devices on LP feedheaters

LP feedheaters are drained by means of drain valves, automatic condensate traps, orifices or syphons. Excessive leakage in a LP feedheater (experience indicates that it never occurs) causes a pneumatic level monitor like in the HP heaters to close the powered check valves (if there are any). The stroke limits of the check valve servomotor are indicated in the control room. An electric level monitor gives alarm if the level continues to rise; automatic bypass equipment is usually not provided on LP heaters, only manually operated valves.

In certain cases a second still higher electric level monitor is installed which acts directly on the vacuum breaking valve.

Protection for special arrangements

A cross connection with a reducing valve 521 between the cold reheat and a lower extraction is switched as follows:

– directly connected to the reheater system on the HP side,

– LP connection located so that two powered check valves in series are located between the reheater and the lower extraction point,

– a non-powered check valve 454 is provided in series with reducing valve 521,

– reducing valve 521 and check valve 454, like powered check valve 502, are placed at least 3 ft. above the highest operating level in vessels 431/433.

Frequently a restricting venturi 461 is installed in extractions to large capacity vessels and HP surface heaters to prevent excessive thrust on the turbine. The same is valid for extractions to evaporators and to feedheaters which could be overloaded under certain operating conditions.

If feedheaters are placed above the turbine pedestal, which would be against our recommendations, an additional powered check valve (max. two in series) is required in each extraction line concerned.

C. Reheat turbines with bypass

The following conditions apply in addition to those mentioned under B.

– Each cold reheat line from the HP cylinder must be provided with one powered check valve operated by the turbine safety oil system 62.

– An extraction from the cold reheat is not provided with safety devices unless there is a feedpump turbine (505 becomes superfluous). The nonpowered check valve 454 would not be provided in this case. Reducing valve 521 would only be closed by signals from level monitor 441.

D. Additional conditions for reheat turbines with feedpump turbines

– Feedpump turbines of plants with a bypass are supplied with steam from an extraction from the main turbine (usually the same extraction which supplies the deaerator). However, the pressure at low loads is insufficient and steam is then taken from the cold reheat [3]. Two powered check valves in series 507, 508 are provided in the extraction to protect the main turbine against steam induction from the reheater. These check valves are closed by the safety oil system of the main turbine. The feedpump turbine is protected against a back flow of water or steam from feedheater 423 by powered check valve 505, or when the feedpump turbine is rated at 40 MW or less by a non-powered check valve in place of check valve 505.

A backflow from feedwater tank 433 is prevented by check valves 502 and 501. Non-powered check valve 454 in series with reducing valve 521 is also provided in this case.

– Feedpump turbines of plants without a bypass are supplied with reduced live steam at low loads. The same conditions as above also apply in this case.

Turbine drains

In the following chapter, the drains which directly concern the turbine are considered.

Basically, it can be said that the number of drains is a good indication of how well a power plant was planned. As these auxiliary systems cause, in addition to their primary task, a loss in thermal efficiency, the aim during the planning should be to keep the number of drain points to a minimum. This can be obtained through the following considerations:

– Extraction lines should be laid out with continuous grades to the feedheaters ensuring self-drainage of the line. Locating the feedheater below the turbine axis makes this possible in most cases.

– The design of the turbine and its individual elements should be carried out with close consideration of potential condensate traps and water collections. The basic design of a reaction turbine casing, as opposed to that of an impulse turbine, greatly simplifies fulfillment of the above requirement.

– The most effective drains are those which prevent the collection of water. This is obtained by ensuring a continuous flow of steam in the possible collection points.

Even when strictly observing these rules there are a number of points in a plant where the installation of drains is necessary. In the following sections, these drains are divided into four groups:

A. Starting drains (see Fig. 3, item *1*)

These drains are solely provided for draining the condensate which collects during heating-up and starting. They are provided with a fast-acting pneumatic shut-off valve with position indication and common control, either automatic or manual. The starting drains are opened before starting the turbine and are kept open until 15% load is reached, independent of the start being a cold or a hot one.

B. Disturbance drains (see Fig. 3, item *2*)

This group contains those drains which are activated only when a secondary plant component is disturbed. The purpose of this type of drain is to keep the extraction line to the isolated element dry by continuous steam flow in the line. The operation of the pneumatic drain valve is automatic by means of the limit switches on the shut-off valve in the corresponding extraction line.

If, for instance, a feedheater is isolated on the steamside, the disturbance drain upstream from the isolating valve is automatically opened as soon as the isolating valve reaches the closed position.

C. Combined disturbance and starting drains (see Fig. 3, item *3*)

In certain points drains are selected to fulfil the function described under both section *A* and *B*. Such a point is for instance the extraction to the deaerator. To fulfil the NPSH demands for the feedpump, the deaerator is placed above the turbine axis which necessarily gives a U-shaped configuration of this extraction. Since this practice is common in Europe as well as in the U.S. it will be necessary to have a drain in the lowest point of the extraction, which is open during starting as well as when the extraction is isolated.

D. Continuous drains (see Fig. 3, item *4*)

This type of drain is mostly applicable in those regions where wet steam is found. The task is to drain water which collects during normal operation. In nuclear plants, they are mostly applied as interstage draining.

For safety reasons, shut-off valves are forbidden in these drains. The capacity is limited by orifices. The diameter of these orifices should be given careful consideration as these drains represent a continuous heat loss.

The next section concerns where the different drains are led.

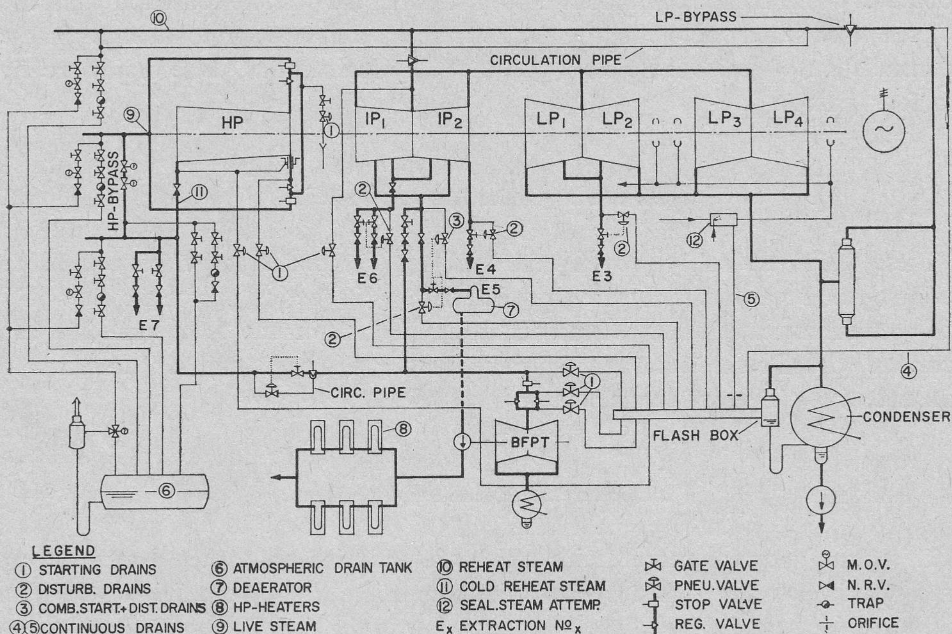

Fig. 3. Typical drain diagram of a reheat turbine with bypass and feedpump

As can be seen in Fig. 3, item *5*, all starting drains for the turbine if they are under vacuum before starting are led to a special collector, the flashbox. All the other drains concerning the boiler are led to an atmospheric drain tank. In nuclear plants with Boiling Water Reactors, where atmospheric flashing is not allowed, a second flashbox is provided.

All drain lines are to be led to the flashbox or the atmospheric drain tank with a continuous grade of at least 2%. These drain collectors are therefore installed in the lowest possible point in the plant.

Function of flashbox

The steam led to the flashbox is cooled to saturated condition with a spray head. Water for the spray is taken after the main condensate pumps.

The water is led to a lowest possible point on the condenser through a 7 - 8 foot high syphon. The saturated steam is led from the top of the flashbox to the condenser neck, according to the principle to lead water to water and steam to steam.

Sealing steam system

The supply system for the glands can be connected to a number of sources. These are usually auxiliary steam, live steam, cold or hot reheated steam or even steam from an extraction. Switch over facilities enable a change from one source to another during operation. Such facilities are most dangerous because a switch-over will suddenly take an isolated line into operation. Thereby collected water will be carried over to the glands and will cool the rotor unsymetrically, causing a bowed rotor with its related severe damage. The danger involved is emphasized by the number of accidents which have already occurred due to such arrangements. A lot of broken shafts due to overstressing as a consequence of water induction are known.

Through suitable measures such damage can be fully avoided. It must be strictly observed that the gland sealing system is supplied from one source only.

The best source is, dependent on the type of boiler, the live steam line or the hot reheat line. The best connection point is in the vertical pipe approximately two feet below turbine main stop valves if live steam is used, and in the vertical pipe two feet below the reheat stop valves if hot reheat steam is used.

The supply line has to be as short as possible and led with a constant grade to ensure selfdraining. This is obtained by running pipe section and between the steam source and supply control valve with an upward grade which will ensure that the line is kept hot, even when the need for supply steam is zero. After the control valves the supply line is to be laid with a constant grade down to the gland steam heater, the lowest point of which should in turn be connected to the flashbox with a continuous drain. (see also Fig. 3, item *6*).

Conclusions

The following is a summary of those points which have been considered most important.

– Principly, every measure aimed at preventing water from collecting or being induced into turbine is always more effective than extensive supervision for the detection of water, because, by its nature, the latter can only react when water is already present.

– Prevention of water induction begins with the planning of the plant. As an example, placement of the feedheaters below the turbine axis is a strong contribution to this point. This generally allows the extraction lines to be planned so that they are self-draining away from the turbine, or making the collection of water impossible.

– Another important preventive measure is the optimal layout and design of the various interconnected devices with respect to safety – e.g. small enclosed volumes for steam and water, no steam inlets below maximum water levels.

– The design of the powered check valves also has an important influence on the plant safety; a gland for instance may not be allowed to restrict the movement of the valve flap. These demands are fulfilled by the check valve shown in Fig. 1, as this has no glands.

– A motor operated valve controlled by a level switch in a feedheater is no protection against reverse flow of cold steam (saturated steam) or carry-over of water caused by a sudden load reduction. A powered check valve will prevent such a reverse flow.

References

[1] J. H. Moore, *How to Keep Water Out of Turbines*. POWER. New York, February 1971.

[2] J. D. Dickinson and D. E. McKindley, *Turbine Effects from Steam and Water Abnormal Cooling*. American Power Conference Chicago, April 1970.

[3] H. J. Mühlhäuser, *Modern Feedpump Turbines*. Brown Boveri Review. Nr. 10, 1971, Baden, Switzerland.

Zapobieganie uszkodzeniom turbin przez uderzenie wodne

Streszczenie

W ostatnich kilku latach w Stanach Zjednoczonych gwałtownie wzrosła liczba przypadków uszkodzenia turbin wywołanego zassaniem wody lub chłodnej pary wodnej. Zapoczątkowało to intensywne badania nad środkami zapobiegania temu, prowadzone zarówno przez użytkowników jak i producentów.

Z amerykańskiej statystyki dotyczącej przyczyn uszkodzeń powstałych po zassaniu wody do turbin wynika, że w ostatnich sześciu latach 25 wypadków spowodowało 23 735 godzin przestoju, z tego 70,4% czasu przestoju wiązało się z zassaniem wody przez rurociągi upustowe.

Przedyskutowano ważniejsze problemy dotyczące zwiększenia bezpieczeństwa działania i dyspozycyjności turbin na podstawie doświadczeń własnych. Poważne źródło zagrożenia wyeliminowano przez celowe umieszczenie podgrzewaczy wody zasilającej, za wyjątkiem odpowietrzacza, pod turbiną. Zapobieganie dostaniu się wody do turbiny zapewnia się na etapie planowania siłowni. Innym ważnym środkiem zapobiegawczym jest rozplanowanie i zaprojektowanie różnych połączonych ze sobą urządzeń w sposób optymalny z punktu widzenia bezpieczeństwa; dla przykładu można tu wymienić małe przestrzenie zamknięte zawierające parę i wodę, brak wlotów pary poniżej maksymalnych poziomów wody.

Zwrócono uwagę, że konstrukcja mechanicznie napędzanych zaworów zwrotnych ma również duży wpływ na bezpieczeństwo siłowni; można na przykład nie dopuścić do tego, by dławik ograniczał ruch klapy zaworu.

Защита от повреждения турбин водой

Резюме

За последние годы в США сильно увеличилось количество случаев повреждения турбин ввиду подсоса воды или охлажденного водяного пара. Это привело к интенсивным поискам средств защиты от таких повреждений. Проводились исследования как у потребителей, так и у поставщиков.

Из американской статистики, касающейся причин повреждений, возникших ввиду подсоса

воды в турбину, следует, что в течение последних шести лет 25 аварий привели к 23 735 часам остановки. 70,4% этого времени было связано с подсосом воды через трубопроводы отборов.

Автор, на основе производственного опыта, предлагает ряд мероприятий, которые могут причиниться к повышению безопасности и работоспособности турбин.

Очень серьезный источник угрозы устраняется при целевом размещении подогревателей питательной воды, кроме деаэратора, под турбиной.

Защита от попадания воды в турбину обеспечивается уже на этапе планирования силовой установки.

Другим весьма важным защищающим средством является надежная распланировка связанных между собой устройств, гарантирующая безопасность эксплуатации. Для примера можно здесь перечислить: малые замкнутые пространства содержащие пар и воду, отсутствие впусков пара ниже максимальных уровней воды.

Конструкция невозвратных клапанов с механическим приводом имеет также большое влияние на безопасность работы силовой установки. Например, можно не допустить до того, чтобы демпфер ограничивал движение клапана.