Discussion of the protection of pressure vessels by using safety valves-rupture disc-combinations

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Due to safety requirements cryogenic facilities are equipped with safety valve-rupture disc-combinations against overpressure. Spring loaded safety valves in combination with rupture discs are designed as the "last resort" in the safety hierarchy to protect life and property. Under certain conditions while discharging, so called fluttering or chattering may occur. This behavior is defined as an extremely opening and closing of the valve. The associated mechanical loads can damage the piping and the equipment or cause pressure oscillations with high amplitudes in the inlet piping to the safety devices. This paper presents safety considerations in cryogenic test facilities for superconducting magnets and shows the reasons, the risks and furthermore the prevention of the oscillations.

CONCEPTUAL DESIGN OF PRESSURE RELIEF SYSTEMS

The consideration of the pressure relief system is an important step in the design of a safe and reliable facility. The conceptual design consists of different steps: At first, a step wise interaction against pressure increase has to be defined (see figure1). Then a decision concerning the location and capacity of pressure relief device has to be made. The selection of the general type of pressure relief devices for each identified location, i.e. safety valve and rupture disc is followed. A further step is the choice of the special features for the chosen devices. At last, in case of releasing medium to the atmosphere, a consideration with respect to economic and environment has to be included.

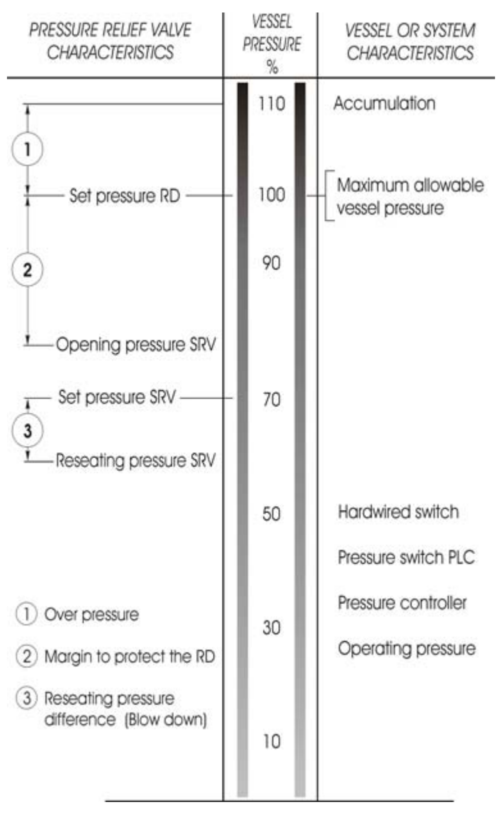

Figure1: Pressure terminology

SPECIFIC CRYOGENIC CONDITIONS

Compared with other facilities, cryogenic plants have specific characteristics. The most noticeable one is the long inlet piping to the safety devices, because the devices are mounted on the warm side of the facility. Another one is the oversize of the safety valve system; usually it is a worst case design with extra charge for not exactly determined conditions. The probable mass flow during discharging is much lower as during the worst case and can be very wide. In addition, at the worst case, pressure rates up to10 bar/s may occur. A further specific peculiarity is the cool down of the inlet piping at the beginning of discharging with very high pressure drop and pressure fluctuations. A validation of the safety system, to ensure that the safety system has the required functionality, is only possible under limited conditions. Therefore, there is less change of a retrofit of the system. The safety devices have to work on the highest safety level with very different real case conditions, however without reliable pretests of the safety system in any case. A risk of loss of coolant caused by an opening of the rupture disc should absolutely minimized, because it produces high costs, needs also a lot of time for bringing the system again in operation and there is also a high risk for contaminations of the cryogenic system.

SAFETY DEVICES

The types of pressure relief devices considered in this paper are limited to a combination of spring loaded safety valves and rupture discs (RD) mounted in parallel on a common inlet piping. In this combination the RD is provided as: an additional safeguard if there are some doubts concerning the efficacy of the safety valve, or to provide additional discharge capacity, or where a larger safety valve may be impractical, the safety valve is designed for a more likely contingency and the RD is designed for the rare contingency, or the pressure rise is too rapid for the safety valve alone. In order to get a safety margin for the protection of the rupture disc, the set pressure of the safety valves is 70% of the burst pressure of the RD. There exists two different types of safety valves, the so called full lift valves (SRV) and the relief devices (RV).

SRVs are characterized by rapid opening or pop action. The valves opens rapidly within 5 % pressure rise, the amount of lift up to the rapid opening should not be more than 20 % of the total lift. The opening times of SRVs are on the same order of magnitude as the burst disc. These are results of new specific investigations on different types of SRVs from different suppliers. The consequences of these astonishing results are discussed in the next chapter.

RVs are characterized by a more or less steady opening in relation to the pressure increase. A sudden opening within a 10 % lift range will not occur without pressure increase. A further distinctive feature is the small coefficient of discharge (about factor 3) compared to a SRV.

RDs are non-closing devices. The thin diaphragm is designed to rupture (or burst) at a determined pressure. They are fast acting safety devices; the rupture time is related to size and burst pressure and in the time range of about 10 msec [7]. There are different discs in use, simple metallic dome discs manufactured on ductile materials, subjected to tension and reverse buckling types, with the dome against the direction of flow. Reverse types are subjected to compression so that the discs inverts fully and than separates from the disc holder. The disc can fully open or remains partly open. Graphite discs are flat, made of brittle material and exposed to tension and shear stress. They shatter almost as soon as the burst pressure is passed and the fragments swept into the downstream piping or in a cage. The subject to premature failures if operating pressure exceeds 70% of set pressure is very important and needs great care as well as the sensitivity of the discs against pressure oscillations and temperature.

SAFETY VALVE OSCILLATIONS

During discharging undesirable instabilities of the valve discs may occur. They are distinguished between fluttering and chattering.

Fluttering frequencies are in the range of approx. 1 Hz. The principal causes are an over sizing of the SRVs or a high pressure drop in the inlet piping. A further reason for flattering is a high back pressure in the outlet piping. In general, this behavior can also be considered as the normal behavior caused by wide flow rates.

Chattering is the more dangerous oscillation, caused by shock waves due to the rapid opening or closing of the valve. Resulting vibrations may cause misalignment, valve seat damage and failure of valve internals and associated piping. Furthermore under certain conditions very strong pressure oscillations in the inlet piping may occur, with chattering frequency in the range of 100 Hz.

There are some design rules to avoid chatter: The 3 % loss rule is the most commonly applied rule in practice [1, 2, 3]. On one hand, the pressure loss of 3 % of the set pressure is allowable in the inlet piping, on the other hand, the difference between the pressure loss in the inlet piping and the reseating pressure difference must amount to at least 2 % of the set pressure for a safe and proper function. This states the International standard ISO4126 as well the American ASME code. This rule is very conservative but independent of safety valve types and behavior [4]. Due to the lack of conclusive experimental evidence, industry has generally accepted this rule as the standard; but to fulfill this rule is very difficult. The consequences are very large diameters of the inlet piping, because the 3 % rule is rated to the maximum flow capacity of the SRVs at the beginning of discharge.

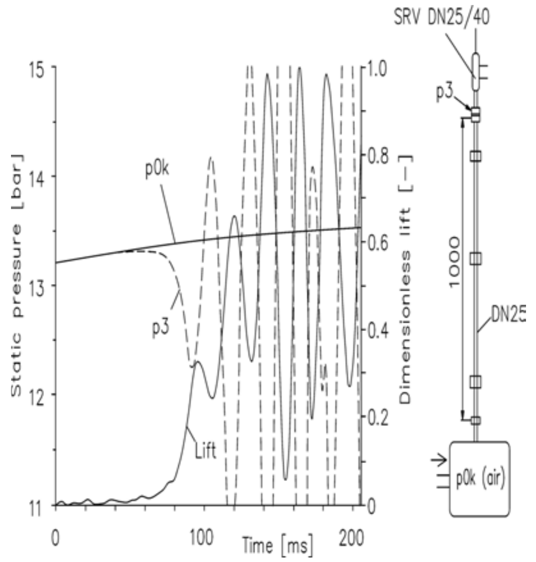

Figure 2: Chattering of SRV

Another criterion is the so called pressure surge criterion [5, 6]. Due to the rapid opening of the safety valves, in form like a pop action, pressure waves in the inlet line are generated and cause chatter under certain conditions. The important parameters are: value of discharge coefficient, flow diameter, length and diameter of the inlet piping, opening time of the safety valve and fluid parameters like sound velocity and density. The opening time of a SRV is an important parameter to avoid chattering. The longer the opening times and the reseating difference, the smaller the probability of chattering. Manufacturer's data and research paper suggest about 20-100 msec for SRVs in normal industrial context. The measured data [7] are contrary to these published statements which makes the probability of chattering much higher. Unfortunately in cryogenic services there are also big changes of the fluid parameters during blow up and there is no experience with this criterion in the cryogenic community.

Figure 2 shows a very impressive example for chattering of a SRV mounted on a test rig [8]. The SRV is mounted on a vertical inlet piping with the same diameter as the nominal diameter of the SRV. The medium is air at room temperature and the pressure drop is about 9 % of the set pressure. As shown in the figure, during the chattering the pressure in the vessel increases and there are large pressure amplitudes in the inlet piping. Such behavior must be prevented in any case, because such pressure amplitudes may be the reasons for unexpected response or injury of the RD.

SUPPLEMENT OF THE SYSTEM FOR AN IMPROVED SAFETY DEVICE ARRANGMENT

For a reliable safety system, flattering or chattering of the valve disc has to be absolutely prevented and therefore special actions have to be taken. A pressure rise must be handled in sequential steps. The first step is on the PLC-level, the second with hard wired pressure switches and at least using safety devices (see figure 1). The installation of the safety devices must be considered as an integral part of the safety system. Important is the reduction of the pressure drop in the inlet piping by careful attention of all the other cryogenic border conditions, like heat input, stiffness of piping or leak tightness. To equip the SRV with an oscillation damper and also with a holdup cylinder is reasonable, because these are two important devices to prevent chattering. The damper is the most effective, reliable and economic method to achieve valve stability. The pneumatic holdup cylinder, triggered by the system pressure, keeps the valve disc for a chosen time in an upper position after a first lifting. Furthermore, an extension of the opening time and an increasing of the reseating pressure difference (blow down) can be useful. A bellow is necessary to compensate the backward pressure and also for the protection of the spring. The over design of the valve capacity must be avoided. This action reduces the inlet piping diameter, because the 3 % rule is capacity related. A separate piping for the RD is recommended, because pressure oscillation caused by chattering is only in the inlet piping of the SRV. There is a reflection of the pressure wave on the nozzle of the inlet piping. A large margin between the set pressure of SRV and RD is necessary. An important action to reduce the loss of coolant after an ignition of the RD is the use of a change-over valve in the inlet piping of the RD. The switch over to the second disc reduces the loss of coolant and prevents the deposit of humidity. After an ignition of the RD, a switch over to the second disc can be done, if the arrangement is equipped with the necessary actuators and sensors (see figure 3). Because of dangerous fragments, a strong cage for the RD is necessary and the mounting position of the RD must be in such a way, that there is no possibility for a deposit of fragments in the system.

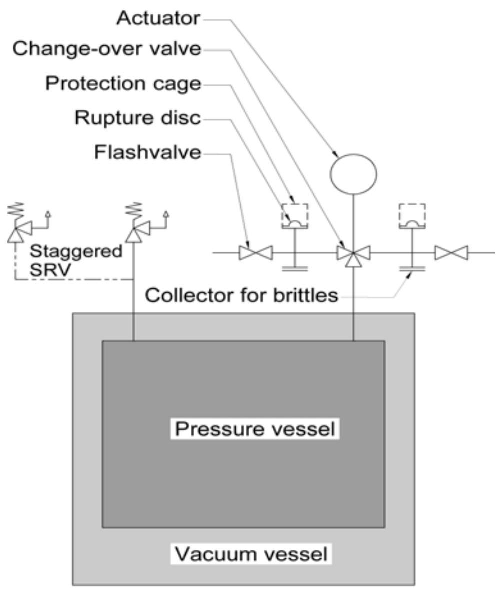

Figure 3: Possible arrangement of safety devices

CONCLUSION

The protection of cryogenic facilities against overpressure with safety valve-rupture disc-combinations includes certain risks. Safety valves manufactured from castings may look not very sophisticated, but in their design, accuracy and function they are delicate instruments and perform an essential role. The installation of safety devices is an integral part of the safety system and must be done very carefully. Special care must be taken in order to satisfy the stability criterion and for the prevention of chattering of the safety valves discs. A broad discussion about safety devices installations is needed in the cryogenic community, because there are not enough information’s published about this topic, even in specific journals.

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