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Safety factors in the design and use of pressure equipment

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Abstract

The paper discusses the role of safety factors in pressure equipment and recommends that there are three main considerations to be taken into account as follows:

(a) Safety factors for pressure equipment should not only give confidence but they also demonstrate the level of confidence.
(b) Safety factors need to compensate for technological and human shortfall.
(c) Safety factors should be related to the hazard of the equipment.

Keywords: Pressure equipment; Safety factors; Public perception; Human error; Consequences

1. Introduction

A general perception is that safety factors are there to provide confidence in the safe use of an engineering component, assembly or system. Pressure equipment by its nature is potentially hazardous and needs factors of safety to provide a margin against failure from uncertainties in design, materials, manufacture, inspection, and subsequently in operation. Do the current factors of safety for pressure equipment provide this confidence, are they consistent with the level of hazard, and are there grounds for changing the balance?

It is possible to identify three different types of safety factor. The first concerns uncertainties in the technology where a full understanding or necessary data is lacking. Secondly, variability in human performance and error is always present and usually sets the limit to which safety factors could be reduced, even with a full knowledge of the technology. In addition to these more tangible aspects, misadventure, possibly defined as a remote but conceivable set of circumstances, needs to be accommodated. In summary, safety factors cover uncertainties in technology, the human element and misadventure.

The public perception of factor of safety is often seen as a factor of ignorance. It indicates the extent to which the designer or user does not have reliable data on the properties and performance of materials or

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on the validity of the calculations or on the behaviour of the system in operation. This definition seems to be crude and incomplete as far as the engineer is concerned since the reality is always more complex and subtle.

Generally, safety factors are perceived to be part of the design process. For example, limits are specified in codes and standards to the ratio of the material's strength to the expected strain or the ratio of the strength of a material to the maximum stress expected in use. However, the margins of security against risk of failure in operation, for instance, from a lack of knowledge of degradation rates, are also safety factors. If safety factors equate to confidence in operation, then in-service inspection intervals to which a component is subjected in turn represent a safety factor albeit of a different type.

Different factors of safety may guard against the same uncertainty. In relation to uncertainty in manufacture, design standards provide for a reduction in the design safety factor with increasing inspection requirements. An example of this is the European Unfired Pressure Vessel standard, EN 13445:2002 [1].

Factors of safety may vary depending on amount and nature of the information available. For pressure equipment in-service in the UK, the Pressure Systems Safety Regulations [2] do not prescribe fixed in-service inspection intervals. They require suitable intervals to be judged by a competent person taking all relevant factors and information (or lack of) into account.

The American, Henry Petrowski made many statements on safety and reliability, two of which are worthy of note in the context of this paper [3]. The first one explains that failure is central to the design process in that more is learnt from failures than from success:

> *The history of engineering is full of examples of dramatic failures that were once considered confident extrapolations of successful design; it was the failures that ultimately revealed the latent flaws in design logic that were initially masked by large safety factors and a design conservation that became relaxed with time.*

The second statement concerns a consistent conclusion of researchers that:

> *Human error is the most important factor in keeping engineering designs from achieving theoretical levels of reliability.*

In the context of pressure equipment, it may be observed both that the rate of failures in the UK is at a very low but not negligible level, and that many of the failures are the result of human error. Does this mean that the factors of safety are not yet optimised? On closer examination, it can be concluded that there is an inherent difficulty in defining and determining factors of safety for pressure equipment and that the perception of a safety factor varies considerably in the public eye and between different sectors of industry.

2. Current provisions

Many of the provisions specifying factors of safety in the pressure equipment sector are either in national and regional legislation or technical codes and standards or quality assurance systems. In the UK, the legislation tends to be goal-setting, specifying responsibilities and what is required to be achieved rather than being prescriptive of the means to achieve the goal. Technical codes and standards tend to cover the technological uncertainty and quality. Conformity assessment procedures have been part of the quality assurance system for many years and are designed to ensure that the requirements of the legislation and the codes standards are met in practice.

The controlling legislation for placing pressure equipment on the market or putting into service within Europe comes from European Union Directives. An important instrument is the Pressure Equipment Directive [4] that is transposed into UK legislation as the Pressure Equipment Regulations [5]. Annex I of the Directive (PED) defines Essential Safety Requirements for pressure equipment but not the means for achieving them. Only in Section 7 are statements made for specific quantitative requirements. Where they are not applied the manufacturer must demonstrate that appropriate measures have been taken to achieve an equivalent overall level of safety. For example, values are given for the general membrane stress limits that must not be exceeded according to the material used. For example: *in the case of ferritic steel including normalised steel and excluding fine-grained steel and specially heat treated steel the limit is the lower of two-thirds of yield stress or five twelfths of the tensile strength*.