1. INTRODUCTION

The operating range, defined by choking and surge is a very important parameter of a centrifugal compressor. A sufficiently broad margin between choking and surge facilitates the operation and control of a system (gas turbine, turbocharger or multistage industrial compressors) in which the compressor is only one component and has an important influence on possible accelerations in non stationary operation.

Most performance prediction methods predict choking in a relatively accurate way but often show large discrepancies in the prediction of minimum operating mass flow. These discrepancies are normally an underestimation of minimum mass flow which leads to unpleasant surprises. A better prediction of minimum mass flow limit is therefore an important task for any designer.

Although surge and stall are very different, these words are commonly used or misused to describe the same unsteady phenomenon. It is therefore important to already give a first definition of what is meant by surge and stall.

In a decelerating flow, boundary layers are submitted to an adverse pressure gradient. The necessary energy to overcome this gradient is transmitted from the main inviscid stream to the boundary layer by viscous or turbulent stresses. When the momentum in the boundary layer is insufficient to overcome this pressure gradient, the flow will separate and local return flow will occur. From a macroscopic point of view, this reorientation of the flow can have a steady characteristic (steady stall) or can be an unsteady phenomenon in which separated and attached flow are alternating (rotating stall). This last phenomenon is due to the fact that local flow separation influences the surrounding flow field in such a way that other separated flow zones of flow separation are created which in turn are influencing the initial separated zone. Stall can occur in the inducer (due to incidence), impeller (jet and wake flow), vaneless diffusers (neg. radial velocity), vaned diffuser channels, scrolls and return channels.

Steady stall (except wake impeller flow) is generally accepted because this phenomenon does not create a dynamic loading of the impeller. However, it is our belief that many compressors operate with one or more components in rotating stall. Centrifugal compressors are often composed of strong components which easily sustain a limited amount of dynamic loading. However, at high pressure levels (typically 300 to 500 bar in reinjection or chemical plant compressors), the pressure fluctuations corresponding to rotating stall become more important and mechanical vibrations do not allow to operate safely under these conditions.

This is illustrated in figure 1a from reference 1 comparing the performance curves obtained under different testing conditions. The minimum operating mass flow, measured during low pressure testing (CO_2, test class III) is lower than the one obtained from high pressure testing (natural gas, test class I). In the latter case, operation had to be limited because of subsynchronous vibrations as shown in figure 1b. These vibrations are due to vaneless diffuser rotating stall. The impact of the corresponding pressure fluctuations can be neglected at low pressure but prohibits to work at high pressure.

Surge is the flow condition in which the whole compressor system becomes unstable, resulting in violent changes of inlet and outlet conditions and an increased noise. The compression system can then be described as a self-sustained flow oscillation in which the impeller acts as an exciter and the rest (inlet and outlet volume, throttle valve and pipes) acts as a resonator. Surge is a system phenomenon, where stall can be considered as a local phenomenon. This does not exclude the possibility that stall has an influence outside the region where it occurs and very often stall is the triggering mechanism for surge. The presence of violent pressure oscillations during surge do not allow to operate the compressor under these conditions unless precautions are taken to avoid mechanical damage of the compressor.

Systematic research on rotating stall and surge started in the fifties on axial compressors and is reported by Kriebel et al. (Ref. 2).

The complexity of the problems, which are not yet fully understood, and the wide variety of geometries in which they occur, have resulted in a large amount of published data, which sometimes lead to contradictory conclusions and prohibit to make a complete survey of this problem. The references used here are those which seemed relevant and were available to us. We are aware that many data are not discussed here but in view of previous comments, this does not mean that they are less valuable.

This discussion is an attempt to classify them in a logical way based on some theories. This was not always possible because some alternative prediction methods and correlations also give good results and do not directly fit in this general theory.

A more detailed definition based on a theoretical description of surge and stall and their main characteristics will be given in the next chapters.

A last chapter contains a discussion of the possible interventions which allow to avoid or postpone the occurrence of these instabilities or to reduce their impact.