A third object of the invention is the provision of a control system with a limited surcharge compared to a control system adapted for avoiding surge conditions.

For meeting at least one of these objects or others, a first aspect of the present invention proposes a method for avoiding stonewall conditions of a constant speed plural stage compressor comprising at least a first stage, a second stage and a first inter-stage line between the first stage and the second stage.

According to this invention, this method comprises the steps of:

a- measuring the temperature at the inlet of the compressor,

b- measuring the ratio between the outlet pressure and the inlet pressure of the first stage of the compressor,

c- calculating a coefficient based at least on the value of the inlet temperature and on the measured pressure ratio,

d- if the calculated coefficient is in a predetermined range, acting on a control valve mounted in a gas recycle line which opens into the first inter-stage line.

This method proposes to act on the working conditions of the first stage of the compressor. The inlet temperature and pressure and also the outlet pressure are measured. If the calculated coefficient is not in the predetermined range, the inlet temperature has to increase and/or the ratio from the outlet pressure by the inlet pressure has to increase.

In a first embodiment of this method, the coefficient calculated in step c may be a coefficient calculated by multiplying the inlet temperature of the compressor by a logarithm of the ratio of the outlet pressure by the inlet pressure.

A preferred embodiment of this method foresees that the coefficient calculated in step c is a head coefficient:

$\Psi = 2 * \Delta h / U^2$

where:

$\Delta h$ is the isentropic enthalpy rise in the first stage,

U is the impeller blade tip speed,

and in that

$\Delta h = R * Tin * \ln (Pout/Pin) / MW$

where:

R is a constant,

Tin is the temperature of the gas at the inlet of the first stage,

Pout is the pressure at the outlet of the first stage,

Pin is the pressure at the inlet of the first stage, and

MW is the molecular weight of the gas going through the compressor.

In this embodiment, it is supposed that the gas is an ideal gas and that the transformation is isentropic and adiabatic. This approximation gives good results into industrial realities.

In step d of the above described method, a control system acts:

- on a bypass valve fitting a recycle line which opens into the first inter-stage line.

In this action, it is possible to increase the outlet pressure.

The invention concerns also a constant speed plural stage compressor comprising:

- a first stage of the compressor,

- at least a further stage of the compressor,

- a first inter-stage line between the first stage and the second stage,

- a temperature sensor for measuring the temperature at the inlet of the first stage,

- a first pressure sensor for measuring the pressure at the inlet of the first stage of the compressor,

- a second pressure sensor for measuring the pressure at the outlet of the first stage of the compressor,

characterised in that it further comprises:

- means for implementing a method as described here above, and

- a recycle line from the outlet of a $n^{th}$ stage of the compressor to the first inter-stage line and comprising a bypass valve adapted for avoiding stonewall conditions.

A constant speed plural stage compressor may be a four-stage or a six-stage compressor.

In a constant speed compressor according to the invention, each stage may comprise an impeller, and all said impellers may be mechanically connected.

These and other features of the invention will be now described with reference to the appended figures, which relate to preferred but not-limiting embodiments of the invention.

Figures 1 to 4 illustrate four possible implementations of the invention.

Same reference numbers which are indicated in different ones of these figures denote identical elements or elements with identical function.

Figure 1 shows a plural stage compressor which is in this example a four-stage compressor. Each stage 10, 20, 30, 40 of the compressor which is schematically shown on figure 1 comprises a centrifugal impeller with a fixed speed. The stages are mechanically coupled by a shaft and/or by a gearbox. The impellers can be similar but they can also be different, for example with different diameters.

A supply line 4 feeds gas to the compressor, more particularly to the inlet of the first stage 10 of the compressor. The gas can be for example boil-off gas from a storage tank on-board a boat or onshore.

After passing through the first stage 10, the gas is feed by a first inter-stage line 12 to the inlet of the second stage 20. After passing through the second stage 20, the gas is feed by a second inter-stage line 22 to the inlet of the third stage 30. After passing through the third stage 30, the gas is feed by a third inter-stage line 32 to the inlet of the fourth stage 40.

After the fourth stage 40 the compressed gas may be cooled in an aftercooler 5 before being led by a supply line 6 to an engine (not shown) or another device.

The compressor comprises a first recycle line 8 which may take compressed gas at the outlet of the first stage 10 and may supply it to the inlet of the first stage 10. A first bypass valve 70 controls the passage of gas through

## CLAIMS

**1.** Method for avoiding stonewall conditions of a constant speed plural stage compressor comprising at least a first stage (10), a second stage (20) and a first inter-stage line (12) between the first stage (10) and the second stage (20), comprising the steps of:

a- measuring the temperature at the inlet of the compressor,

b- measuring the ratio between the outlet pressure (Pout) and the inlet pressure (Pin) of the first stage (10) of the compressor,

c- calculating a coefficient ($\Psi$) based at least on the value of the inlet temperature (Tin) and on the measured pressure ratio (Pout/Pin),

d- if the calculated coefficient ($\Psi$) is in a predetermined range, acting on a control valve (76) characterised in that said control valve is mounted in a gas recycle line (74) which opens into the first inter-stage line (12).

**2.** Method according to claim 1, characterised in that the coefficient ($\Psi$) calculated in step c is a coefficient calculated by multiplying the inlet temperature (Tin) of the compressor by a logarithm of the ratio of the outlet pressure by the inlet pressure (Pout/Pin).

**3.** Method according to claim 2, characterised in that the coefficient calculated in step c is a head coefficient:

$\Psi = 2 * \Delta h / U^2$

where:

$\Delta h$ is the isentropic enthalpy rise in the first stage,

U is the impeller blade tip speed.

**4.** Method according to one of claims 1 to 3, characterised in that in step d, a control system (90) acts on a bypass valve (76) fitting a recycle line (74) which opens into the first inter-stage line (12).

**5.** Constant speed plural stage compressor comprising:

- a first stage (10),

- at least a further stage (20, 30, 40, 50, 60),

- a first inter-stage line (12) between the first stage (10) and the second stage (20),

- a temperature sensor (78) for measuring the temperature (Tin) at the inlet of the first stage (10),

- a first pressure sensor (80) for measuring the pressure (Pin) at the inlet of the first stage (10),

- a second pressure sensor (82) for measuring the pressure at the outlet of the first stage (10),

characterised in that it further comprises:

- a recycle line (74) from the outlet of a $n^{th}$ stage to the first inter-stage line (12) and comprising a bypass valve (76) adapted for avoiding stonewall conditions, and

- calculation means and control means (88, 90) for implementing a method according to one of claims 1 to 4.

**6.** Constant speed plural stage compressor according to claim 5, characterised in that it is a four stage compressor.

**7.** Constant speed plural stage compressor according to claim 5 characterised in that it is a six stage compressor.

**8.** Constant speed plural stage compressor according to one of claims 5 to 7, characterised in that each stage comprises an impeller, and in that all said impellers are mechanically connected.