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Industrial Compressor Anti-Surge Computer Control

Ventzas Dimitrios, and Petropoulos George

***Abstract*—**The paper presents a compressor anti-surge control system, that results in maximizing compressor throughput with pressure standard deviation reduction, increased safety margin between design point and surge limit line and avoiding possible machine surge. Alternative control strategies are presented.

***Keywords*—**Anti-surge, control, compressor, PID control, safety, fault tolerance, start-up, ESD.

I. Introduction

THE compressor is a multi-stage type; the incoming air is compressed in the first stage and then passed through a heat exchanger to be cooled off before being injected into the next stage, see Fig. 1.

Anti-surge control system design practices encompass the proper sizing, selection, and location of piping of the recycle loops, the recycle valves, volumes of vessels in the recycle path, check valves, etc..

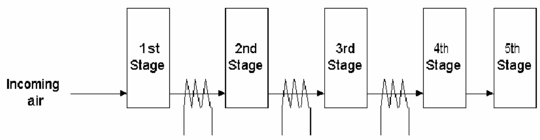

Fig. 1 Compressor details

II. Instrumentation and Actuators

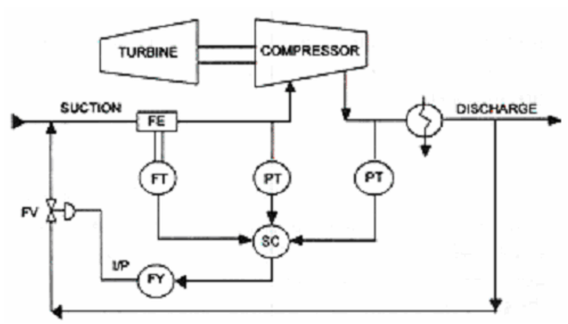

Fig. 2 Required input signals

Ventzas Dimitrios is with Department of Informatics & Communications, TEI of Larissa, Larissa 41 100, Greece (e-mail: dventzas@uth.gr).

Petropoulos George, Associate Professor is with Department of Mechanical Engineering, University of Thessaly, Greece (e-mail: gpetrop@uth.gr).

The input signals are the suction flow differential pressure, suction pressure and discharge pressure, see Fig. 2. A temperature measurement corrects flow and speed at the compressor suction.

Surge detection devices are static and dynamic ones. The pressure transmitter monitors the pressure and controls the blow-off valve to avoid stall and surge. *Surge cycles* occur fast and can even go undetected if the applied instrumentation and controls are too slow.

III. Compressor Surge

Compressor surge occurs when the developed compressor head (H) drops below the network resistance (discharge pressure). Surge is a *fluctuation* of *flow* and *pressure* and it causes overheating and damages; it may be violent enough to damage a compressor in a few cycles. Surging gives cyclic flow, back-flow, high vibrations, pressure shocks and rapid temperature increase. Process design minimizes the piping volume in the recycle and forward path [1].

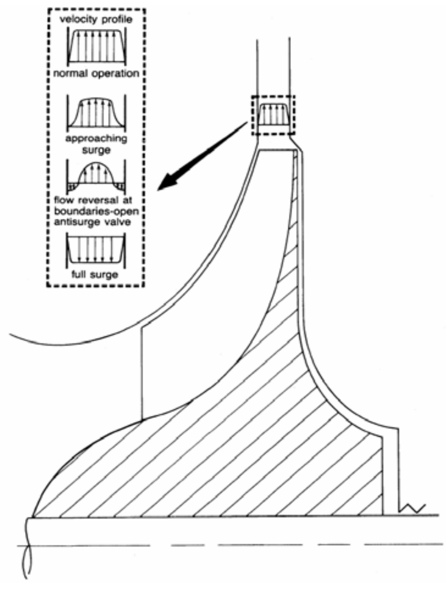

Fig. 3 Momentary flow reversal

An increase in pressure across the compressor, results in a momentary *flow reversal*, see Fig. 3. This *surge cycle* goes until a change is made in the process conditions. The controller operates a surge valve to maintain sufficient forward flow to prevent surge, see Fig. 4; the external *causes-effects* are:

- bad machine design, system *damage*
- improper *assembly*, mispositioned rotor
- restriction in suction or discharge
- internal plugging of flow passages (fouling)
- process conditions upsets, sudden load change
- inadvertent loss of speed
- changes pressure,temperature,gas composition
- instrument or control malfunction
- hardware malfunction (variable inlet vanes)
- de-tuned controller
- operator error
- the *inability of the cold recycle valve* to quickly and effectively de-pressurise the large volume in the cold recycle flow loop, etc

Surge is detected by

1. *the boundary layer reversal*
2. *the compressor 2nd harmonic excitation*

The model features are inlet flow, gas parameters, molecular weight, pressure and temperature, compression ratio, shaft power in steady-state and transient conditions.

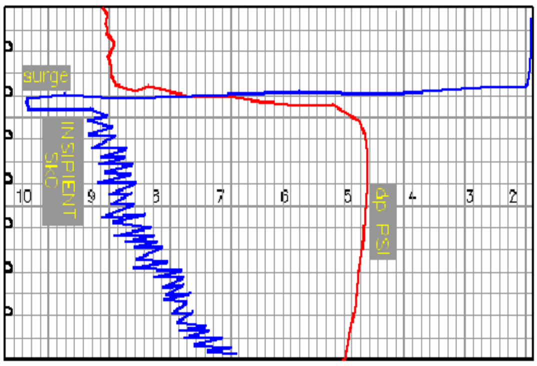

Fig. 4 Actual surge test results of opening / closing the recycle / suction valve

IV. Anti-Surge Computer Control

The methods for accomplishing surge control are a *blow-off to atmosphere* or *recirculation* from the compressor outlet to the inlet, see Figs. 5, 6, 7. It tries to keep the flow and pressure within the area under the curve, see Fig. 8. Look-ahead setpoint, adaptive gain, open-loop response techniques are incorporated. In case of imminent surge, monitored by ΔP(F), the anti-surge value opens, recirculates gradually the gas and returns it to non-surge region. The anti-surge control is capable of coping with *rapid flow fluctuations* and *process gas variations*. Surge controller in *worst-case operating conditions* can result in inefficient compressor operation and wasted energy [2].

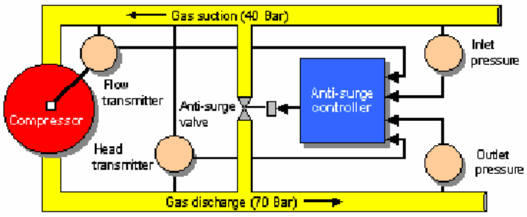

Fig. 5 Anti-surge controller

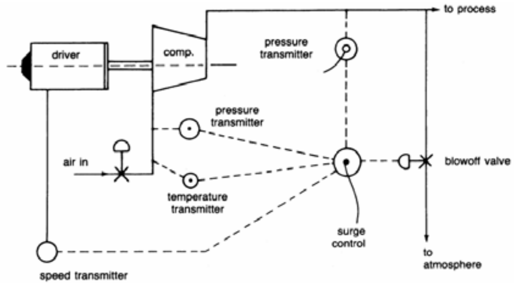

Fig. 6a Pressure oriented anti-surge control system

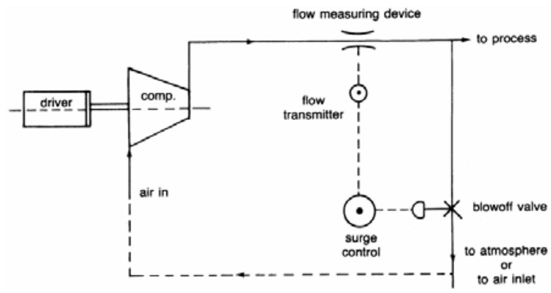

Fig. 6b Flow oriented anti-surge control system

In the surge control map the compressor flow set point is provided by the control line positioned to the right of the surge line which provides a safety margin for the surge PI controller output to the surge valve to prevent the flow from decreasing below the control line, resulting in a safe relationship between the control line and the surge line, see Fig. 8. Surge control action is initiated at the control line by opening the surge valve as required to maintain forward flow through the compressor; this prevents a further shift of the operating point to the left towards surge [4], [5].

The method automatically compensates for changes in molecular weight, temperature, compressibility, pressure and compressor rotor speed. It utilizes a characterization of compression ratio (P_d/P_s) vs compensated inlet flow function $(h_s / P_s)^{1/2}$ as control parameters. The algorithm allows minimized recycle or blow-off flow. This method reduces the initial cost and simplifies engineering, testing, operation, and maintenance [6].

Different control algorithms can be configured such as:

1. standard PID-type algorithms
2. generic antisurge controller
3. purpose-built anti-surge controller
4. advanced controller
5. predictive controller

6. a multivariable control system
7. DVP (Dynamic Valve Positioning)
8. Event-controlled an expected valve position
9. response line adaptation (up to 10 lines)
10. temperature and/or speed correction
11. optimum control trimming of each actuator
12. Partial Opening: activated by the first surging.
13. Full opening: activated by "surge protection "
14. Event-controlled -change-over
15. ESD compressor protection
16. effectiveness of the hot and cold recycle loops
17. retardation-free pressure-limiting control
18. minimization of the dead-time
19. surge *spike counter* and *alarm functions*

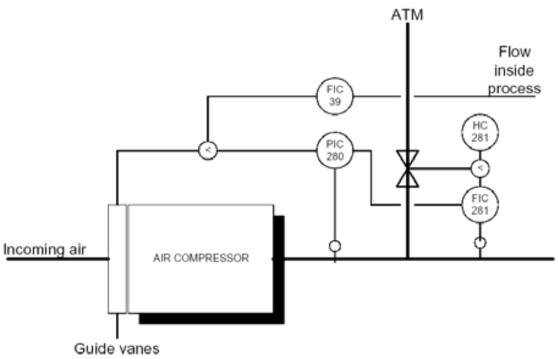

Fig. 7 Control Strategy

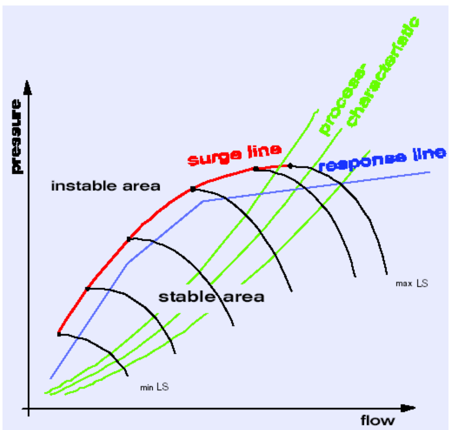

Fig. 8 Compressor performance map

Initial surge curves are derived from manufacturer data, see Fig. 8. Suction and discharge valve closure tests are performed at constant compressor speed. The operating curve of a compressor is divided by the surge line into a stable and an instable area caused by a decrease of the flow quantity or an increase of the discharge pressure. Surge curve verification is needed, since the actual compressor surge limits differ significantly from the surge limits indicated by the compressor map and approximations and inaccuracies lead to non-reliable control.

The software uses specialized turbine and compressor control functions. Software development for the control system primarily involved configuring and testing proven software function modules. Transitions from “auto” to “manual” or conversely “manual” to “auto,” are bumpless [3].

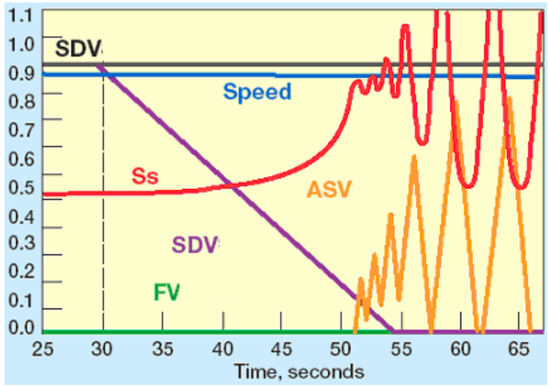

Fig. 9 Operating parameter trends for suction valve discharge (SDV) - cold recycle (ASV) - suction valve (SDV)

Simulation extends data available, field experience and engineering common-sense in:
—ESD while operating in steady-state
—Full closure of the compressor discharge valve
—Full closure of the compressor suction valve

A “proximity to surge” variable, SS [7], describes the location of the compressor’s operating point as compared to its surge limit; if SS < = >1, the compressor is operating in the safe zone, at the surge limit. in the non-stable zone, see Fig. 9.

V. PID Control

The controller needs to be slow for normal operating conditions, but fast when needed to protect the compressor from surge. *Derivative action* makes the system unstable. Tuned PID algorithm might prove to be totally ineffective for some disturbances varying in size, speed, etc. The *look ahead setpoint* positioning (hover) is based on the rate of change toward the surge line. Adaptive set point control prevents surge until the cause of the instability can be corrected. Process compressor capacity or load control comes from a *cascade* loop which determines the speed setpoint.

The performance curves of compressors are flat near the surge, i.e. a small pressure increase can drive quickly toward surge. The *adaptive gain* is a special *PI anti-surge control algorithm* that increases the speed of response without distortion in normal conditions. The controller gain is increased when the operating point is less than the anti-surge setpoint (2.5% < the surge control line).

With *larger and/or faster disturbances*, it may be necessary to manipulate both the *hot and cold recycle valves* simultaneously. In such cases, the hot recycle valve will open for a very short time, arresting the movement of the operating point towards the surge limit. Thus, the control strategy employed is to use the cold recycle loop exclusively to protect against *small disturbances* and the hot recycle loop to protect against *large disturbances*. Once the disturbance is sufficiently arrested, the hot recycle valve will close to prevent overheating the gas at the compressor suction, while the recycle flow required for safe operation is slowly transferred to the cold recycle loop. The two controllers (the hot-recycle anti-surge controller and the cold-recycle anti-surge controller) collaborate to provide *effective* and *efficient* anti-surge protection.

Initial tests revealed that the *cold recycle* valve, should be adequate to protect against *slow disturbances*, while both the *hot and cold recycle* valves may be required for protection against *fast disturbances*.

The *PID controller* acts on the error between the compressor's operating point and the surge control line, and no action is taken until the operating point moves to the left of the control line. The *purpose-built controller* uses a combination of closed-loop, open-loop, and anticipatory control responses, each with different tuning and control points; these algorithms allow the controller to begin moving the recycle valve even before the operating point crosses the surge control line resulting in higher effectiveness.

The controller modulates the cold recycle valve in an effort to move back into the stable operating zone; this results in aggressive valve movement and unstable operation, see Fig. 9. Anti-Surge Control & Surge Protector are available with many *PLCs,* without the need for additional external hardware.

VI. Safety, Fault Tolerance, Start-up, ESD

In order to improve responsiveness the system *surge protection* features include:

- *Surge characterization*
- *Choice of* Δp *vs h or Pd/Ps-1 vs hc algorithms*
- *If a surge occurs, the surge safety margin readjusts*
- *Active control line "hovers" to actual operating point*
- *Non-symmetrical opening and closing*
- *Equal percentage valve linearization*
- *Recycle valve "dumps" or opens immediately*
- *Independent P term forces recycle valve open*
- *speed monitor*
- *autonomous over-speed protection*
- *sequence-of-event reporting (1 ms)*
- *fault-tolerant strategy and configuration*

The startup of the turbine is accomplished by initially setting the maximum limit for the inlet valve. The extraction valve, is adjusted to satisfy the initial "horsepower demand." On ESD, the anti-surge valves are opened and go full open based on their stroke times. *Shaft deceleration rate* on ESD is 4% per second. Fail-safe fallback strategies are used in transmitter failures.

The *master discharge pressure controller* is not reliable, should be very fast and designed for continuous override control and safely implemented by engineers with little compressor control experience. Two out of Three (2oo3) voting architecture, maximise system availability without compromising safety. The application (IEC-61511) software (IEC-1131) offers on-line programme changes, on-line diagnostics with 100% system emulation capabilities. The hardware (IEC-65108) is safety integrity level certified to SIL 3, making it suitable for mission critical machines, can be replaced on-line and maintains compliance to several international standards. Process limit *overrides*, high discharge *temperature*, high discharge *pressure* and low suction pressure conditions have priority over other speed or flow demands.

VII. Conclusion

Anti-surge control results in standard deviation of master pressure fluctuation compared to pre-shutdown operation reduced from 0.4 barg to 0.1 barg. Anti-surge curves fitted on compressor controller increased safety margin between design point of compressor and surge limit line by about 10%, maximizing throughput from compressor and avoiding possible machine surge with a wider margin from surge control line.

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D. E. Ventzas (1956) is Electronic Engineer and Professor of Technological Institute of Larissa, Greece. He owns an MSc in Control Eng and a PhD in Microprocessor based Instrumentation from Bradford University, Yorkshire, UK. He was Instrument and System engineer in Hellenic Aspropyrgos Refinery, Athens. His research interests are Control and Instrumentation, Biomedical engineering and Computer Tools for Instrumentation. He is SMISA, MTEE.

G. Petropoulos (1959) graduated from the Department of Physics, School of Applied Sciences at the Aristoteles University of Thessaloniki, Greece, in 1983. He was awarded a PhD in Mechanical Engineering from the School of Engineering, Department of Mechanical Engineering, in 1991. From 1984 until 1993 he worked as a research assistant and as a research associate in the Laboratory for Machine Tools and Machine Dynamics in the Department of Mechanical Engineering. From 1992 until 1995 he was a visiting Professor of Tribology in the Technological Educational Institute of Piraeus. Since 1995 he is Lecturer and Director of the Laboratory of Manufacturing Processes in Dynamics of Manufacturing Processes in the Department of Mechanical and Industrial Engineering at the University of Thessaly. The research interests and activities of G. Petropoulos involve Theory and Technology of Machining Processes, Tribology, Metrology, Machine Vibrations. He is a member of the Union of Greek Physicists, EEEE (Hellenic Operational Society, a member of IFORS), Balkan Tribological Association, ASME (American Society of Mechanical Engineers), Greek Metallurgical Society. He is reviewer in the Journal of Industrial Lubrication.