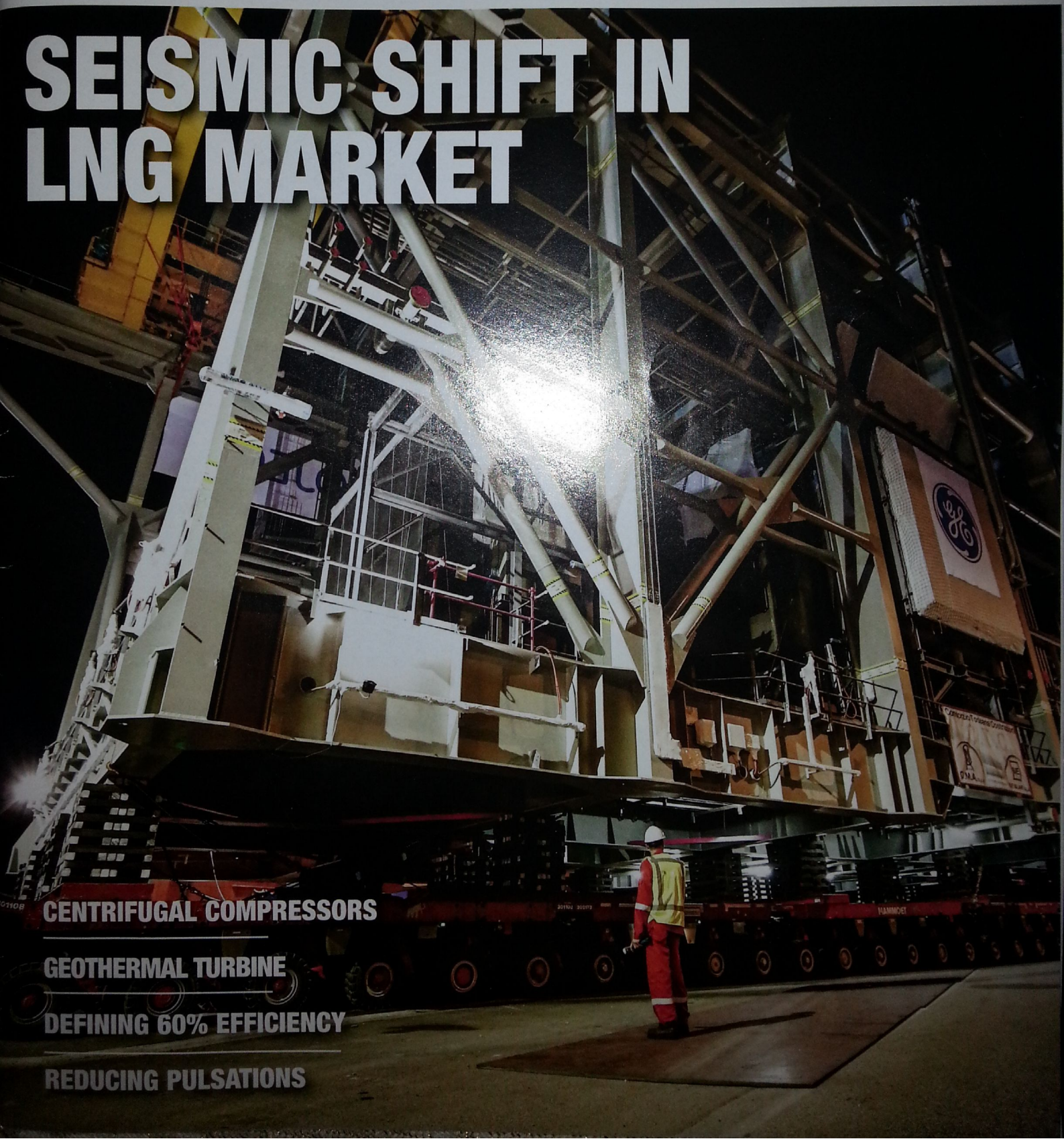
THE GLOBAL JOURNAL OF ENERGY EQUIPMENT

International Turbomachinery

MARCH/APRIL 2013 • VOLUME 54 NUMBER 2 • $7.50

www.turbomachinerymag.com

SEISMIC SHIFT IN LNG MARKET



CENTRIFUGAL COMPRESSORS

GEOTHERMAL TURBINE

DEFINING 60% EFFICIENCY

REDUCING PULSATIONS

Generated by CamScanner from intsig.com

PROTECTING HIGH-PRESSURE CENTRIFUGAL COMPRESSORS

A SOFTWARE ALGORITHM CAN PREDICT PERFORMACE UNDER VARYING THERMODYNAMIC AND INLET GAS CONDITIONS

MASSIMILIANO DI FEBO AND PASQUALE PAGANINI

If inlet conditions in a low-pressure centrifugal compressor change there is a reduction in operating efficiency but no surge problem; in a high-pressure compressor, however, variations in inlet condition can introduce an error of more than 30% (greater than the usual safety margin of 10%).

As a result, protection systems may become inefficient and this could potentially damage the compressor. Using the correct software algorithm, however, it is possible to predict the performances of a centrifugal compressor under varying thermodynamic and inlet gas conditions. These predictions have been found to be accurate at high pressures.

Centrifugal compressor anti-surge protection systems are based on the Surge Limit Line (SSL). SSL is the description of the surge point locus and, in current practice, it is assumed to be invariant regardless of centrifugal compressor inlet conditions. A numerical study was done to investigate the effect of inlet condition variations on the SLL.

Protection methods have been designed with the intention of running the compressor safely by preventing it from nearing surge points. One such method for anti-surge systems would consist of opening, partially or totally, a control valve (anti-surge valve) located on a line that recycles the gas from the discharge to the compressor suction. In this way, the control system could reduce the overall line resistance and increase the elaborated flow, moving the compressor operative point to the right of the characteristic curve corresponding to the actual operative speed (Figure 1).

The anti-surge valve is commanded by a dedicated proportional–integral–derivative controller (PID controller), usually embedded in the protection system Programmable Logic Controller (PLC). The surge protection logic embeds the SLL and the correlated Surge Control Line (SCL) (Figure 2).

Using field readings, the protection logic calculates the actual operative compression ratio and uses the stored SCL data to determine the corresponding actual flow limit parameter. This value is then used as a set point for the anti-surge valve PID controller. The process variable is the actual flow parameter obtained from field readings.

It is evident that surge protection systems rely on the SLL concept, which is the central element of the system's protection action. The SLL is a simplified correlation between the compression ratio and the flow parameter that identifies the surge points (for a detailed description of the math involved in these calculations, as well as gas mix details, contact the authors at the email address below). Introducing a simplifying approximation, it is possible to obtain the SLL final expression as a correlation between the flow parameter and the compression ratio:

$$\frac{\Delta p}{p_1} = K \cdot (\beta - 1)$$

This expression of the SLL seems to be

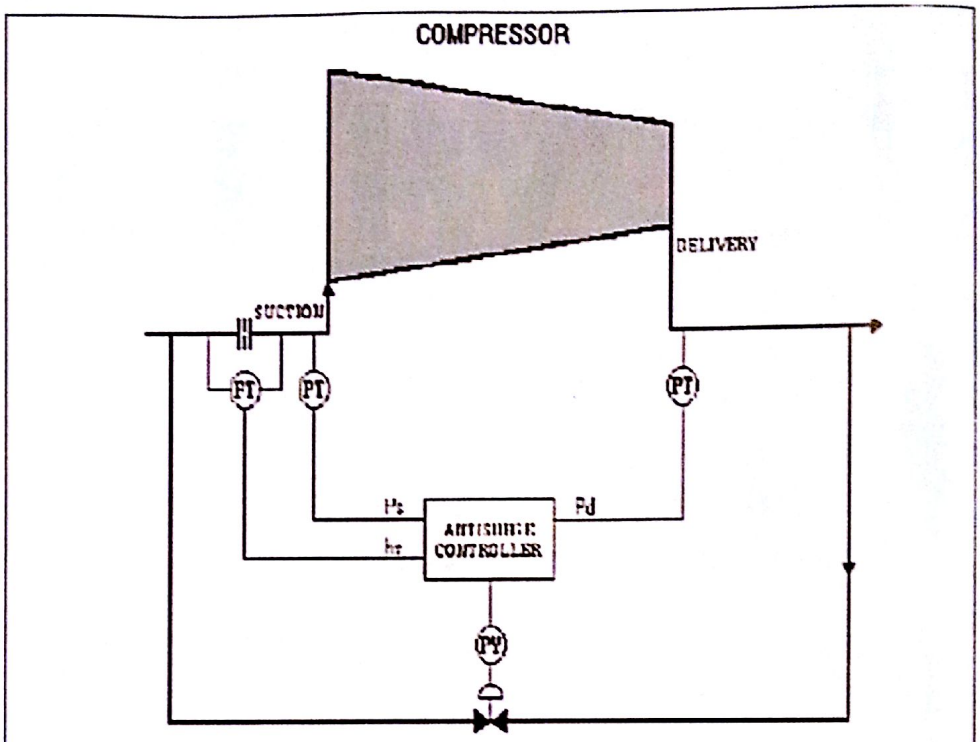


Figure 1: A typical plant layout where there is a recirculation line that includes an anti-surge valve

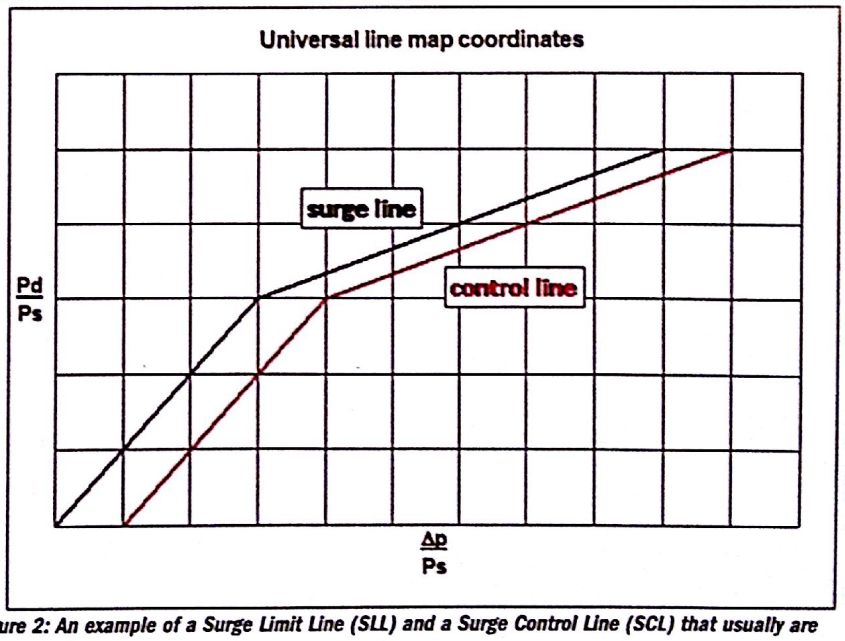


Figure 2: An example of a Surge Limit Line (SLL) and a Surge Control Line (SCL) that usually are calculated with a 10% flow safety margin

Generated by CamScanner from intsig.com

invariant for gas inlet conditions (hence it is sometimes called the "Universal Surge Line") and this enables it to be easily implemented on process computers. This seemed to be an advantage in the early stages of anti-surge applications (the nineteen sixties), when engineers were looking for a simple surge locus formulation to be implemented with a modest calculation capability. While it is still used today, it has some limitations.

It is possible to argue that:

1) The $H_p - Q$ flow curve depends on the gas suction condition

2) The affinity law is valid for liquid flow, and can be considered applicable to gas for low compressibility flows, i.e., low Mach flows

3) When applicable, the affinity law is valid in a small range around a reference point and cannot be used to describe the overall range of the compressor surge point without violating the applicability limits of the hypothesis.

Based upon these considerations, it can be seen that the SSL depends on inlet suction conditions. These are applicable for single-stage compressors operating at low Mach numbers. For multi-stage compressors and those running at higher Mach numbers, it should be considered a surge locus; also, the true surge locus depends upon the actual behaviour of the gas, i.e., inlet pressure, temperature and gas mix composition.

Therefore, a better equation to calculate the surge point is

$$\frac{\partial\left(\frac{P_d}{P_s}\right)}{\partial \dot{V}} = 0$$

Where

P_d= Discharge pressure

P_s= Suction pressure

$\dot{V}$= Volume flow

For off-design inlet conditions, a compressor performance map can be calculated using Cmap, which is not based on the affinity law or other approximations, but on the availability of a non-dimensional model of the compressor using correlations of work and flow coefficients parameterized by Mach number.

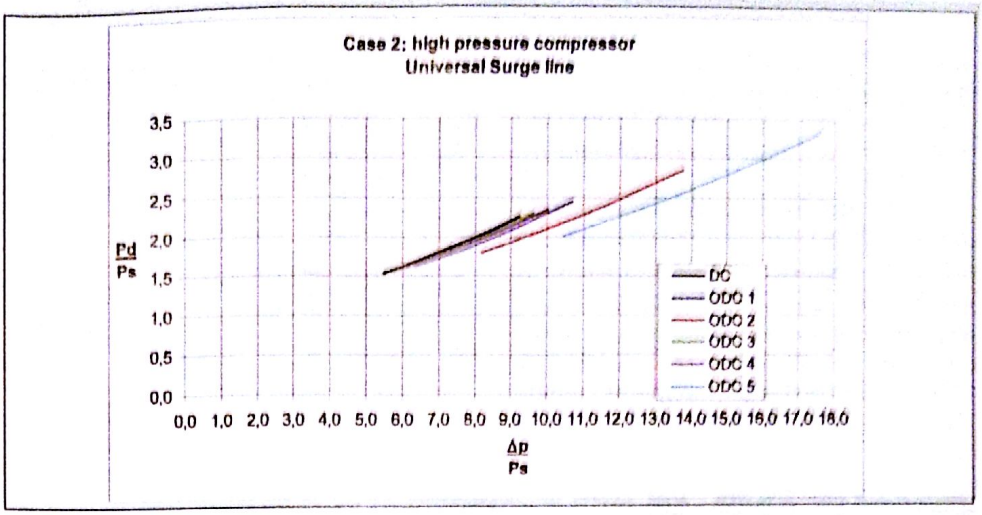


Figure 4: Surge limit lines for different inlet conditions

The surge line can then be worked out from the compressor performance map with reference to inlet off-design conditions. Consequently, two surge lines (DC and ODC) can be drawn having the ratio between p across the orifice and the suction pressure (Ps) on the x-axis, and the compression ratio (Pd/Ps) on the y-axis (Figure 4).

-DC (Design Condition)

-ODC (Off Design Condition).

Compressors with low-pressure suction

In this case study, a centrifugal compressor is running at various inlet conditions. Starting from DC, the surge line has been calculated based upon a changing molecular weight (ODC 1 and ODC 2), pressure (ODC 3), temperature (ODC 4) and both properties (ODC 5) (Figure 3).

It should be noted that for various ODC points, the maximum error calculated is 2.6 %. If, however, the variation on the inlet conditions is applied simultaneously on pressure, temperature and gas mix, the maximum error rises to 7% (with a compression ratio of 3.5).

Compressors with high-pressure suction

Starting from DC, the surge line has been calculated in this example based upon a changing molecular weight (ODC 1 and ODC 2), pressure (ODC 3), temperature (ODC 4) and both properties (ODC 5) (Figure 4).

It can be noted that for ODC, the maximum error calculated is 18.6 %. If the variation on the inlet conditions is applied simultaneously on pressure, temperature and mix, the maximum error rises to 31.2% (compression ratio of 2.7). It is interesting to note that the correct surge flow line moves to right with respect to the design surge line. This implies that the control system is underestimating the surge flow. Therefore, the compressor could potentially be exposed to surge events.

Note: All calculations in this study were executed using Cmap, a dedicated software tool developed at IPC (Industrial Plant Consultants) Research Lab to predict the performance of centrifugal cmpressors under different operating conditions. TI

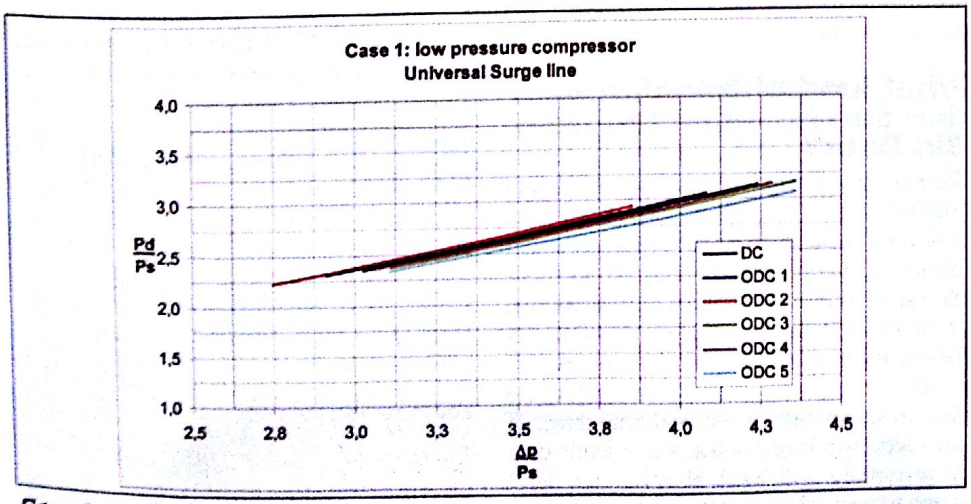


Figure 3: Surge limit lines for different inlet conditions

Author

Massimiliano Di Febo is Operation Manager for IPC. He holds a masters degree in mechanical engineering and is a registered professional engineer in Bari, Italy.



Pasquale Paganini is Technical Manager for IP.CHe holds a master degree in mechanical engineering. For more information visit www.ipc-eng.com.

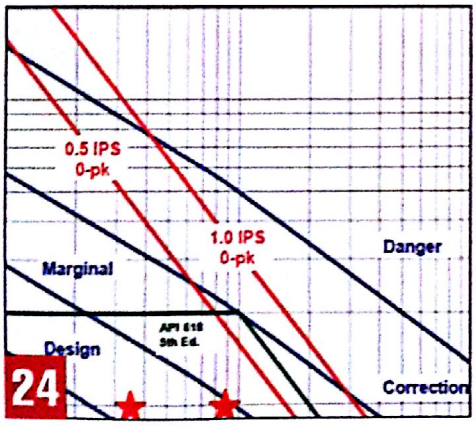


Generated by CamScanner from intsig.com

INTERNATIONAL
Turbomachinery







30 **Q & A**
Megatrends impacting oil & gas industry
Dan Heintzelman, President & CEO GE Oil & Gas, talks about industry drivers, turbomachinery technology and the growth of unconventionals.

31 **New Products & Services**
- GE's single-shaft Integrated Compressor Line
- Blue-C compressor
- Triconex Safety View
- Motor cooling system
- Redundant valve manifold
- Reducing gas turbine NOx
- LM6000 test cell
- Hybrid control system
- New Invensys suite
- Spain opts for wave power
- Protecting GE control systems
- Thermal history coatings
- Soft foot corrections
- Scalance controller

Features

Cover Story
18 **Seismic shift in LNG market**
Demand is spurring development of new turbomachinery trains, while future U.S. exports promise lower prices.
By Drew Robb

Show Report
22 **GE Oil & Gas Annual Meeting 2012**
The latest trends in power generation, oil production, subsea exploration, unconventional fuels and diagnostics.
By Drew Robb

Renewable Energy
23 **Axial turbine for low-grade heat sources**
A vapor expansion turbine in the 500 kW to 5 MW range has been developed for Organic Rankine Cycle applications.
By Ryan Elliott

Compressors
24 **Reducing pulsations in compressor piping**
Pressure fluctuations from reciprocating compressors can lower the efficiency of centrifugal compressors operating in parallel.
By Eugene Broerman, Klaus Brun, & Kirk Mueller

Oil & Gas
28 **Protecting high-presssure centrifugal compressors**
How to predict performance under varying thermodynamic and inlet gas conditions.
By Massimiliano Di Febo and Pasquale Paganini

Generated by CamScanner from intsig.com