A. Brighenti, S.A.T.E. s.r.l , Italy, L. Manara, Peroni Pompe S.p.a., Italy, and M. Schirru, Sarlux S.r.l., Italy, look at solving a pressure pulsation problem on a visbreaking TAR pumping system at the Saras refinery in Sardinia.

This article presents a problem solving case by means of a numerical dynamic analysis applied to a visbreaking TAR plant that is part of a high technology refinery in Sardinia, Italy. Its TAR pumping system was subject to severe mechanical vibrations which, after a preliminary analysis, were suspected to be excited by internal acoustic resonances in the piping, due to the inherent pulsating flow of the pumps.

Dynamic analyses of the pressure pulsations in the pumping system were then performed to verify the acoustic resonant characteristics. These confirmed that, under certain conditions, they were close to the frequencies of pulsating signals harmonics generated by the reciprocating pumps, despite the presence of pulsation dampeners. A thorough study based on dynamic analyses to find a solution compatible with the space constraints, reliability and minimum impact on the pumps performances was then started in order to redesign the pulsation dampeners necessary to lower the critical pulsations under the limits recommended by the reference API 674 standards[1].

The methodology for the analysis illustrated in this article is not novel by itself, and it has been presented previously by the main author in previous papers with reference to application in gas compression plants[2 - 4]; however, the case illustrated here differs from those others by the type of fluid handled by the plant, for which reliable data on the speed of sound (or the

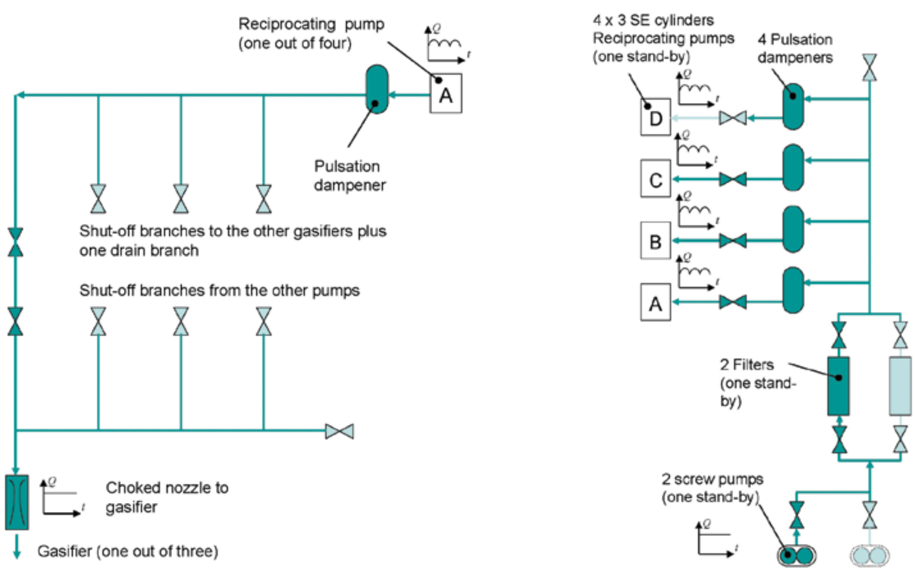

Figure 1. Scheme of the pumping plant following one of the possible suction side (right) and discharge side (left) configurations.

Table 1. Pump characteristics	
Average suction pressure (absolute)	0.7 - 0.8 MPa
Average discharge pressure (absolute)	4.2 - 4.6 MPa
Average temperature (suction and discharge)	200 - 230 ˚C
Number of pistons (each pump, single effect)	3
Piston diameter	150 mm
Piston stroke	175 mm
Volumetric efficiency	0.96
Crankshaft obliquity ratio	0.186
Mass flowrate (at 100 rpm)	13 kg/s

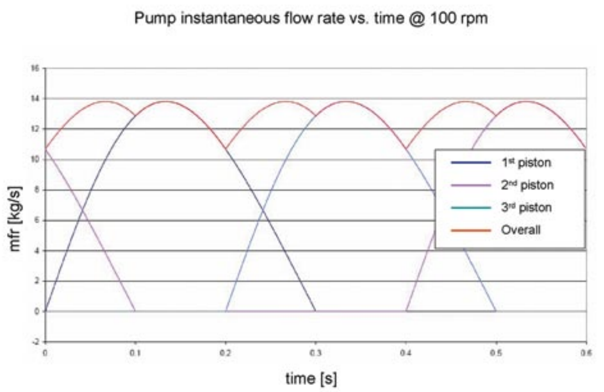

Figure 2. Instantaneous mass flowrate vs. time by each piston and by a single whole pump (upper envelope) of the TAR pumping plant.

bulk cubic compressibility that allows its calculation) were not available at the high pressures and temperatures characterising the process, namely at the conditions for which visbreaking TAR is in fluid state.

Other critical aspects to be considered in the mechanical design of the pulsation dampeners were the high value of the operating temperatures, the variation of the average suction and discharge pressures, due also to seasonal changes in the process and to changes of the feed charge to the refinery.

Furthermore, the many combinations among pumps and gasifiers in operation determined various and different resonant characteristics of the plant, and thus a narrow useful set of ranges for the design frequencies of the dampeners, on their own function of the speed of sound in the pumped fluid.

Plant description

The plant processes hydrocarbon (visbreaking TAR) with three gasifiers, which are part of the integrated gasification combined cycle (IGCC) system owned by Sarlux at the Saras refinery in Sarroch, Sardinia.

The pumps, which generate pulsating flow and pressure, are volumetric piston type. The pumped fluid is a heavy residuum of the refinery distillation process similar to tar, with a density of 850 - 1050 kg/m^3 and viscosity of 150 - 200 cSt at 225 ˚C, very dense at ambient temperature. The TAR is kept at the high operating temperature of the process by means of heated and thermally insulated pipes.

Due to the relatively low compressibility of the fluid, the reciprocating pumps generate an instantaneous flowrate independent from the upstream and downstream pressures, with average and harmonic components determined primarily by the swept volume, the shaft speed and the crankshaft obliquity ratio.

The speed can be considered constant at given operating conditions, but may purposely and slowly vary with time, following process control needs, by variable speed electric motors. The nominal value considered in the case examined is 100 rpm.

Due to this pressure independent characteristic, unlike gas compression plants, the dynamic analysis of the suction and discharge side plant can be performed separately, from the viewpoint of the internal acoustics. Indeed, no acoustic resonance generated at either side can be propagated to the other side by the pump, which instead acts as a bidirectional acoustic wave generator with independent propagation patterns. The pump characteristics are shown in Table 1.

There are four possible system configurations (piping-pump) on the suction side, since one out of the four pumps is in standby, three of them being in operation, connected in parallel to a common header (Figure 1, right); depending on the one that is on standby, a change in the piping network geometry occurs.

However, there are 12 possible discharge configurations (pump-piping-gasifier), as each of the four pumps can be connected to independently feed each of the three gasifiers of the plant, by appropriate combination of shut valves selections (Figure 1, left).

The lengths of the main lines and of the dead branches of the piping connected to the pumps change greatly from one combination to another: from 84 to 96.5 m at the suction and from 90 to 123 m on the discharge, the pipes with diameters of 8 -12 in. and 6 - 12 in. respectively.

The geometric changes highlighted above imply a large variability of the internal acoustic characteristics of the piping, namely the natural modes and frequencies of the characteristic acoustic waves, thereby leading to different response patterns for the same dynamic input by a pump.

In addition, the speed of sound through the fluid may change on a long term basis due to the different crude oils treated by the refinery and the process settings. In pressure pulsation analyses it is normal to consider a range of values for this parameter, over which sensitivity analyses are performed, in order to obtain pulsation dampeners suitable for the range expected.

However, in the case presented here, the addition (to the already wide variation of operating conditions) of another (typically 5%) uncertainty to this parameter would prevent an acceptable dampeners design, from both a technical and economic point of view. Therefore an accurate direct measurement of the sound speed needs to be carried out for the actual process pressures and temperatures and with various samples of the fluid, taken sufficiently at intervals.

Sound speed measurements

Measurements of the sound speed through the TAR were commissioned to Istituto Elettrotecnico Nazionale Galileo Ferraris[5] prior to finalising the analyses of the plant and the remedial actions needed. A test set on a first sample was performed along a mesh formed by six isothermal lines (120, 150, 200, 220, 240 and 260 ˚C) at five different pressures (0.1, 0.2, 0.4, 0.8 and 1.2 MPa). As this latter value was lower than the maximum needed to cover the whole range of operating conditions in the real plant, the test at 220 ˚C was extended up to 5 MPa but with a different fluid sample, extracted from a different TAR charge. This allowed verification of the repeatability of the measurement method[5]. For example, Figure 3 shows the results obtained along the atmospheric pressure and along the isothermal at 220 ˚C.

It is remarkable that the temperature has a much greater influence than the pressure on the speed of sound. Indeed, this varies by as much as 10% in the 200 - 230 ˚C temperature range of operation, while its variation within the operating

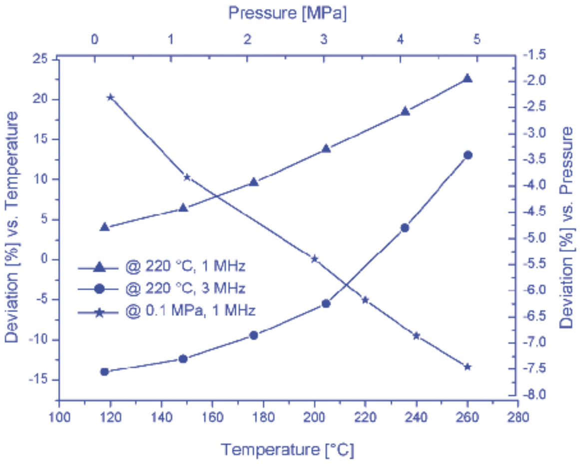

Figure 3. Variation of the sound speed in the process fluid (TAR), as a function of temperature (at constant pressure) or pressure (at constant temperature). The variations are expressed as a percentage of the reference value at the pumps discharge conditions (temperature 220 ˚C and pressure 4.2 MPa).

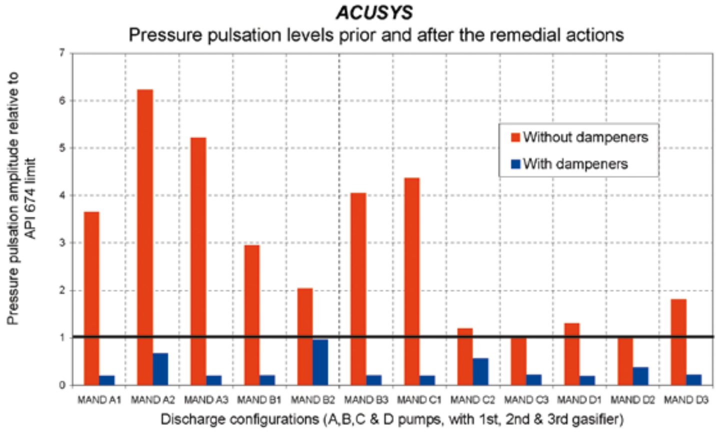

Figure 5. Discharge piping: reduction of the amplitude of the critical harmonic of the generated pressure pulsation obtained by the pulsation dampeners (blue columns), compared with the pulsations occurring prior to the plant modification (red columns) for each of the 12 discharge piping configurations. The values are expressed as ratio to the limit calculated according to API 674-sec.3.6 [1]. In all cases the critical harmonic is 10 Hz.

Figure 4. Picture of one pumping unit prior (left) and after (right) the plant modifications (in foreground: discharge side; in background: suction side). The suction dampener is approximately 2.5 m high; the discharge dampener is approximately 4 m high.

pressures range of the respective suction/discharge sides is less than 0.5%. Figure 3 also shows a second plot (at 3 MHz frequency of the apparatus used to make the measurement). This was checked for the dispersivity characteristic of the fluid, i.e. the sensitivity of the speed of sound to said frequency, which arises at very high values but are of no concern for the range shown by pressure pulsations generated by the pumps[5]. The curve obtained at 1 MHz was thus taken as reference for the analyses.

Pulsation problem solutions

The high temperature, beyond 200 ˚C, prevented the possibility of applying inert gas and membrane dampeners, both at the suction and at the discharge of the pumps. Even the greatest performing synthetic membranes for gas-liquid segregation could not withstand such high temperatures on a multi-year basis, as requested.

On the other hand the dampeners previously used on the suction side by the plant operator, based on pneumatic buffers with inert gas in direct contact with the TAR, proved unsatisfactory as the gas dissolves in the liquid quite rapidly, causing the gradual loss of the damping effect by the dampener. Furthermore, during depressurised operations the gas could also expand into the main line, causing the pumps cavitation.

Another solution, technically feasible in principle and examined during this project, is based on metal spring loaded bellows separating inert gas from the liquid (certainly compatible with the process temperatures). However, this would imply a pressure control of the gas mass charge in the dampener, which balances the process pressure changes, adding to system complexity and a potential fault source to the plant through the presence of active devices.

Finally, the preferred solution for the design of the dampeners, despite the large size needed as a result of the high bulk modulus of the fluid, consisted of totally passive buffers filled with single phase fluid (i.e. the TAR itself); they also have suitable internals that create series/parallel acoustic capacitance and inductance characteristics, which act as reactive impedances, tuned across suitable centre frequencies.

The suction dampeners are like Helmoltz resonators (i.e. with a choke pipe and a capacitance of suitable dimensions, connected as a dead branch in parallel to the main pipeline and close to the suction flange of each pump). On the other hand, the discharge dampeners are similar to internal combustion engine mufflers[6,7] (i.e. they are made by a vessel with internals creating a combination of series and parallel fluid paths along which the acoustic waves are dampened). This internals geometry was necessary to limit as much as possible the overall size of the vessels, which is still remarkable (Figure 4) compared with the suction ones.

Remedial actions

The results of the dynamic analyses (Figure 5), performed prior to the dampener design finalisation, showed that fundamental reductions could be obtained by appropriate selection of the type, positioning and sizing of these elements.

The sensitivity analyses (Figure 6), performed against the variation of the speed of sound in the fluid, also confirmed the need to base the calculation on a reliable value of this quantity. The wide variation of the critical harmonic for certain piping configurations is evident when the speed of sound varies as little as 3%. The design calculations of the dampeners were therefore performed with reference to a suitable envelope of conditions. The dynamic analyses also allowed calculation of the shaking forces generated at the nozzles and internally to the dampeners, so that the consequent fatigue calculations could be more reliable.

Conclusion

The TAR pumping plant, which previously suffered mechanical vibrations under certain operating conditions, was effectively modified by the addition of pulsation dampeners of adequate size and design. The effectiveness was proven not only by the analyses but also finally confirmed by the actual operation which was much smoother than before the modifications.

An essential part of this work was the consideration of the sensitivity to the speed of sound, which required accurate measurement, by a repeatable methodology and with different fluid samples at the high process temperature, prior to finalising the dynamic analysis and the design of the pulsation dampeners. The amplitude of the critical pressure pulsation harmonic could vary by more than 100% even for a speed of sound variation of less than 2 - 3%.

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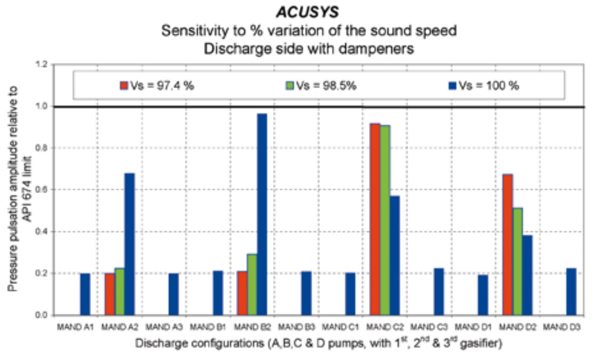

Figure 6. Discharge piping: sensitivity analysis of the amplitude of the critical harmonic to the speed of sound 'Vs' in the fluid, expressed as ratio to the nominal design value (100%). In all cases the critical harmonic is 10 Hz.

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