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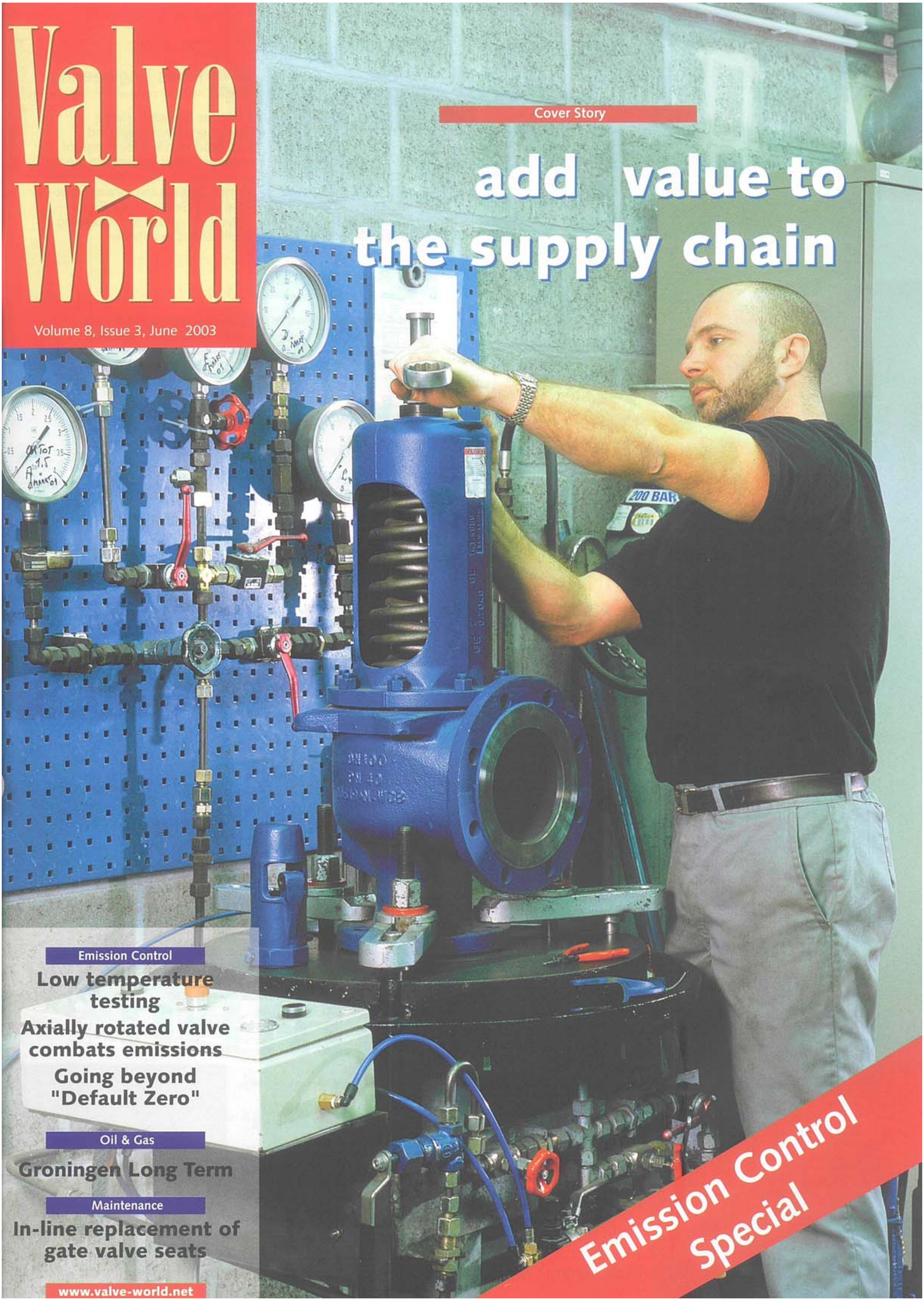

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Thickness sizing of graphite sheets for piston valve seat rings

In a previous article (Valve World, October 2002, page 35) we described the wide range of applications offered by the piston valves, emphasising the new technology used to manufacture the key component of such valves, that is the seat ring of graphite and metal layers. To be effective in various operating conditions, this apparently very simple ring needed a very detailed theoretical development and a long series of tests and measurements. This paper describes some aspects of such development whilst refraining from all the mathematical details involved (these can be found in the full version of this text on the Valve World website).

By Mr Raffaele Angelini, Cesare Bonetti SpA.

Let us describe the problem in its steps:

1) Graphite piston valve rings made of pure expanded graphite in their standard height are rapidly destroyed by erosion;
2) The assembly of graphite layers separated by metal rings yields no improvement if the graphite layers are still thick (say 3 mm or more), since we would again be in the situation under 1);
3) To reduce the shear effects the graphite layers are made thinner and thinner;
4) If the graphite layers are too thin, the portion protruding from the metal rings towards the piston may be cut and ejected by pressure when the valve is closed, so that the tightness is lost;
5) Challenge: find a graphite layer thick enough to avoid the problem mentioned under point 4), and sufficiently thin to satisfy the requirement included in point 3).

It is well known that valves are installed components which often have to meet contradictory performance requirements: producing flow but not reduce head values, reducing fluid pressure, evaporating, not evaporating, not cavitating, controlling flow and even more, depending on plant requirements. In the end, after having been open under erosion conditions, the valve is required to stop the flow with strict tightness. This is the problem.

Given the problem, it is worthwhile going through the mathematics and technology to find a solution or, taking an easier route, to consider just the premise and jump to evaluating the conclusion. We will restrict our analysis within the range of the piston valves (see Figures1 and 1a), a rather old series (invented 90 years ago), but still quite often used given its various advantages.

Graphite gasket material

Experience has shown that only limited use can be made of expanded graphite as gasket material for piston valve seat rings. In fact, despite its sealing quality - one of the best among today's tightening materials - in a broad range of operating conditions, expanded graphite is practically excluded from commodity valves produced in large series. This is due to the poor resistance of graphite against fluid jet erosion and shearing stress, whereas an isolating valve may be required

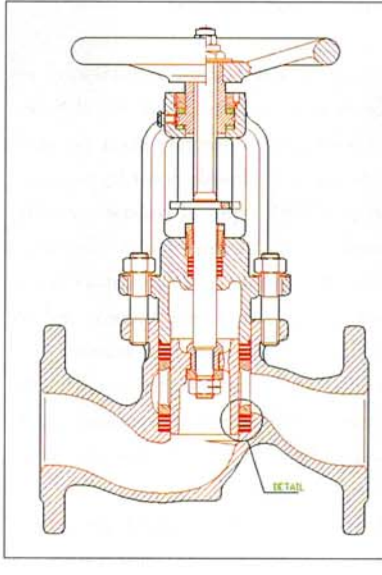
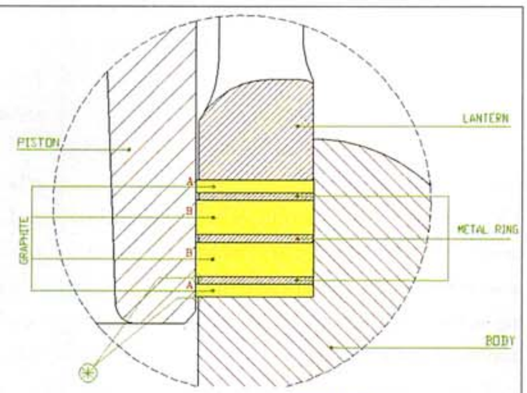


Fig. 1: Cross-section of a piston valve, unbalanced piston design.



	RESISTANCE	
	EROSION	SHEAR
CASE "A"	SATISFACTORY (FLOW JET HAS SHORT CONTACT WITH GRAPHITE)	UNSATISFACTORY (INSUFFICIENT THICKNESS)
CASE "B"	UNSATISFACTORY (FLOW JET HAS PROLONGED CONTACT WITH GRAPHITE)	SATISFACTORY (ADEQUATE THICKNESS)

*ANULAR SECTION WHERE PRESSURE YELDS SHEAR

Fig. 1a: Detail of a piston valve

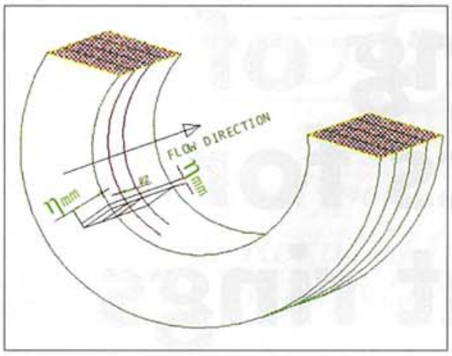


Fig 2: Thickness sizing of graphite sheets

at any time to tighten a vessel, whether or not it is under no flow and pressure conditions or after a high pressure fluid flow has crossed its seat. In the latter case, the tightening surface of graphite is certainly damaged and a leakage will occur, making the valve unacceptable.

Graphite layers, whose thickness corresponds to the length of the fluid path through the seat (approximately 10 mm), became deeply eroded in a short time by the fluid flow under a relatively low pressure.

Assembling several graphite layers with metallic rings placed between them is not a solution as such, since by reducing the graphite thickness the graphite shearing stress and strain in the proximity of the metal/graphite connection surface is not eliminated. This is because the metal and the graphite should undergo an identical strain, but the Young modulus of the first material is around a hundred times greater than that of the latter, thus trending to create a sort of local critical stress which can be reduced making the layers thinner. On the other hand, a graphite layer which is too thin cannot cope with the shearing stress imposed by static pressure when the valve is closed.

Thus we have to determine whether a thickness value can be estimated where the strain is so limited, the weakness induced by shearing is so reduced, and the operating condition is so close to that of simple pressure load, that erosion cannot be initiated; on the other hand, the tightness is safely guaranteed when the valve is closed under pressure.

Such a determination and calculation is the purpose of this analysis.

Moreover, since erosion by liquids is much greater than that of gases or vapours (all other operating conditions being equal), liquid flow only is being considered here. Obviously, we do not take into consideration various different technologies, such as the one where the metal sheets are pierced "grater" type, since there is no reason for this treatment, and we experienced that the scrapes against the piston and the holes through the graphite lead to piston damages and stuffing leaks.

Experimental results

Over and beyond the commonly accepted technical principles, the following points, all checked by experiments and instrumentally measured, are set out below:

-Graphite elasticity compression modulus E is negligible in comparison with that of stainless steel (2,000 and 200,000 N/mm2, respectively: when considering the graphite strain, metal strain is not taken into account);

- Graphite elasticity shear modulus G µE is not much less than/and not equal to the compression modulus E (the expanded graphite sheet during the production and assembling of seat rings is pressed to such a level that it will withstand the shearing stress in operation and at the same time maintain an elasticity sufficient to permit the necessary tightness when the valve is shut off);
- Anisotropy of graphite rolled sheets affects our calculation at two different degrees: a) the direction of the fluid jet crossing the graphite rolled surfaces, b) the orientation of rolling, which makes the cylindrical surface resulting from construction circular cutting non-homogeneous.

Point a) yields a systematic reduction of resistance to erosion throughout 360 degrees and no reduction of graphite shear resistance when the valve is closed; point b) yields a reduction of both types of resistance, with minimum and maximum each 90 degrees. Therefore the annular graphite layers are assembled with different orientations, and we take the anisotropy effect into account by means of factors related to the worst conditions, which allow the max operating parameters to be kept safely below the values tested or calculated.

- Both graphite modula G and E are constant within the pressure/temperature operating range delimited by the ANSI 800 rating of carbon steel, united with the ANSI 800 rating of stainless steel and are therefore within all other ratings included in this union.

Within the range indicated above, the relation of graphite stress versus strain is linear; that is, the parameters are constant (Hook's Law is valid).

Central assumption

And now, the central assumption (experimentally verified, as indicated above) which is the base of the whole calculation:

- Due to the graphite's flexibility, the shear stress is not constant in each section but changes according to a linear

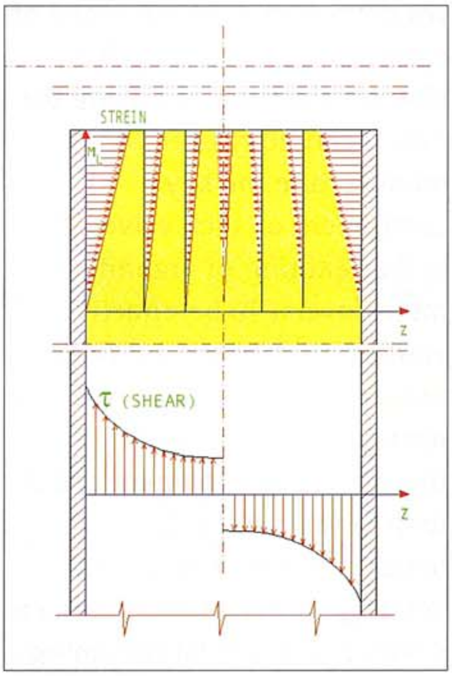


Fig 2a: Thickness sizing of graphite sheets

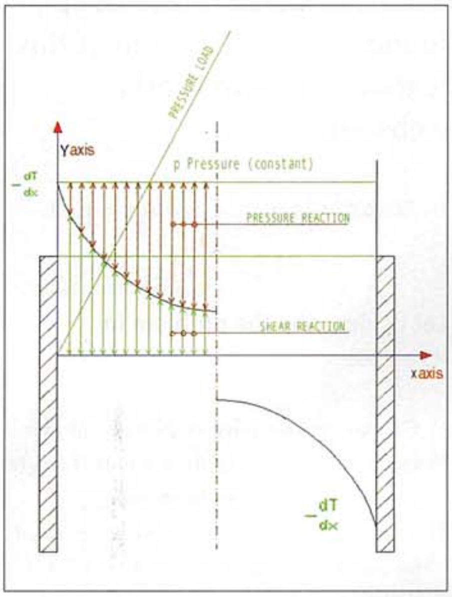


Fig. 2b: Thickness sizing of graphite sheets

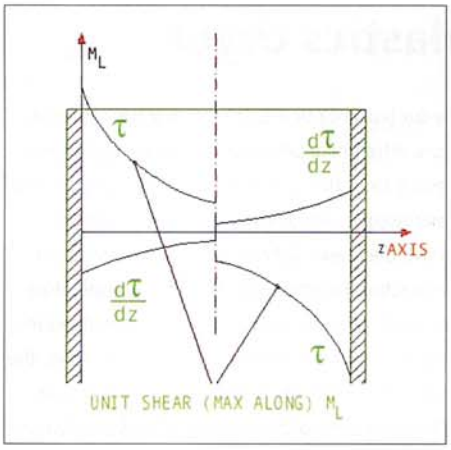


Fig. 3: Thickness sizing of graphite sheets

function of depth, starting from a maximum in the medium confining surface to zero in an internal point of the graphite (towards the outside of the ring) which distance (max depth η) has been measured for the maximum rating pressure: such linear function for shear stress/strain is, on the other hand, in agreement with (and also determined by) the deformation imposed by pressure, which in a homogeneous material (as graphite is along the concerned direction) is linear decreasing (the pressure being constant through the layers, whilst the shear stress decreases). As a first order approximation, we consider the distance η constant along the whole thickness (Figures 2, 2a and 3).

The calculation is developed, as of course all calculation based on strain/stress relationship, taking into account that, locally, the univocal leading parameter is the strain. The other parameters, i. e. pressure, integral forces, balancing reactions/momentum and local shear, will comply with the relevant equations just including the strain parameter.

We apply the various equations considering the case of turbulent flow starting with the relationship between flow jet velocity and inlet/outlet differential pressure in a fitting piece or valve, particularly with atmospheric outlet pressure and an inlet pressure equal to or more than 0.6 N/mm^2.

In this way:

- the whole operating condition range defined at the beginning is covered (minimum rating, PN 6)
- flow rate and velocity depend on the inlet pressure only.

Graphite strip

The analysis is carried on considering a strip of a graphite layer, 1mm wide, with a length along the axis to be determined (the required layer thickness) and a depth to be determined also, corresponding to the distance from the contact fluid/graphite to the point where the shear stress linear decreasing along the radius is null (see Figures 2, 2a and 3). We obtain an elementary beam, where the load and momentum are in no point balanced by tensile stress, only by the preloading of graphite, where we have to evaluate the different shear value due to the load distribution. The beam "length", the layer thickness, is calculated through:

- (1) evaluation of pressure loading along the beam length (the layer thickness)
- (2) the momentum progress of the pressure loading along the beam
- (3) along the same axis, the shear force progress (derivative of (2)
- (4) the integration of the shear stress along the radial axis, which must be equalised to (3).

After various passages, the stability of the strip above defined is stated by a second order differential equation and its physically possible solution.

As expected, the maximum shear value is in the connection metal/graphite and depends on the layer thickness. In order to obtain the fluid veil near the seat and avoid erosion (Figure 4), the shear stress must be much less than the limit shear stress of graphite. This indicates that the layer should ideally be thin, as we knew since the beginning, but now we dispose of the formula of shear decreasing versus thickness.

Then we have to evaluate the layer thickness necessary to resist the shear stress given by the static pressure when the valve is closed, which indicates the layer should be thick and obviously, we dispose of the simple formula of shear resistance versus thickness.

Crossing the two conditions we are lucky enough and find a range of values satisfying both of them. The range is rather restricted, almost critical, although workable from the manufacturer's point of view, and covering all the pressure range stated at the beginning, that is from zero to over 100bar.

The other main parameters selected to manufacture the whole range of ring sizes and compatible with the temperature/pressure ratings stated above are:

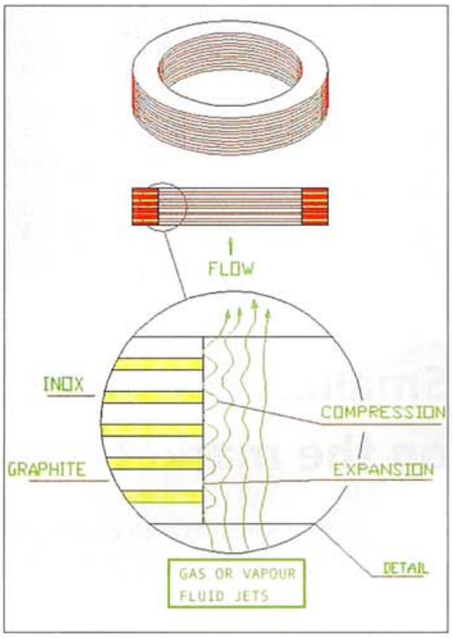


Fig. 4: Thickness sizing of graphite sheets

$E=1500\text{-}2000N/mm^2$
max op pressure=max shear stress: $14N/mm^2$.

Note: it is possible to operate at a higher pressure (up to $25N/mm^2$) as long as special precautions are taken.

Conclusion

For all seat rings, all sizes, all operating conditions (any fluids except oxygen, pressure up to 100bar, temperature up to 550°C) same graphite thickness! We are confident that, given the very simple conclusion and the considerable advantages achieved, readers will forgive us the cumbersome theory and the time spent in the various tests will be compensated. ■

About the author

Mr Raffaele Angelini, who graduated in 1959, has been dealing with design of automatic devices such as control and safety valves transmitters, gauges, etc, since 1963. He is currently involved in the development of instrument lines, including low noise control valves high differential pressure valves, glass and magnetic level gauges.