Critical Pressure-Velocity Values of Carbons for Mechanical Seals Evaluated by Thermal Shock Testings

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In the previous report[1], we presented a method to evaluate the critical PV-values of carbon materials for mechanical seal as a function of the thermal shock resistance according to the theories by Mayer[2] and Golubiev[3]. Their theories, however, do not always correspond to the actual phenomena of failures in the mechanical seals. The most leakages are due to local failures which are caused by local thermal stress, contact stress and so forth on the sliding face of carbon ring. In this report, we discuss on a cause of the local failure named blister on the sliding face of the mechanical seal as the thermal stress problem by a local heating of a thick disk model. Then, the critical PV-values of the mechanical seal are defined in two ways from the failures at the center of blister and the adjacent edge of the seal ring and are expressed as functions of the material parameters of the thermal shock fracture toughness[4] ∇ ($= K_{IC}k/E\alpha$, K_{IC}: mode I fracture toughness value, k: thermal conductivity, E: Young's modulus and α: thermal expansivity) and the thermal shock resistance[5] Δ ($=\sigma_t k/E\alpha$, σ_t: tensile strength). These experimental values of ∇ and Δ of eleven kinds of carbon materials are compared with their practical performances as the mechanical seal.

When we observe the sliding face of carbon of mechanical seal, which was out of order of the sealing capacity, we catch sight of locally lusterless parts and/or crackings at the adjacent edge of the ring. According to the microscopic observations, the lusterless parts involve many small pits and fine crackings linking among pits. Then scanning by a roughness meter on the parts, slight bulgings to extent of 1 - 2 μm are found. For this reason, the parts are called "blister". Such blisters and crackings of carbon become a cause of leakage in the mechanical seal. They occur due to severe operations of mechanical and thermal conditions. Mayer[2] and Golubiev[3] recommended carbon materials having larger values of thermal shock resistance.

Three dimensional unsteady thermal stresses of a thick disk heated by an eccentric circular heat source are analyzed recently by Takeuchi, et. al.[6]. Fig. 1 shows the circumstance of the disk in this thermal stress problem regarded as a part of a ring. Limiting at the adjacent part of the heat source, the thermal stresses may be approximated to the case of the sliding ring. In this figure, a/R and e/R are ratios of heating radius and eccentricity of heat source in the disk of diameter 2R and thickness 2L. Q_0 shows heat quantity for unit area and unit time. Nondimensional circumferential and radial thermal stresses on the radius existing a circular heat

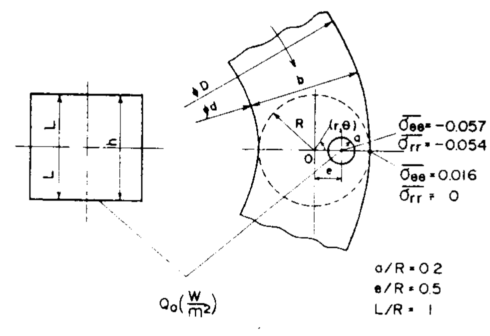

Fig. 1 Simulation of blister on the contact face of mechanical seal by thermal stress in locally heated disk model.

source in Fourier number $\tau = 1$ are shown in this figure. Here the nondimensional thermal stress $\bar{\sigma}$ represents.

$$\bar{\sigma} = \sigma(1+\nu)/EK, \quad K = \left(\frac{1+\nu}{1-\nu}\right)Q_0\alpha R/k \tag{1}$$

Thermal stress distributions after $\tau > 0.5$ almost saturate to the maximum values. At the center of the heat source $\bar{\sigma}_{\theta\theta\ max}$ and $\bar{\sigma}_{rr\ max}$ are together compressive. But at the outer edge of the disk adjacent to the heat source, $\bar{\sigma}_{\theta\theta}$ becomes the maximum tensile and $\bar{\sigma}_{rr}$ becomes zero. Stresses on the radius at opposite side are negligibly small. Now if there is an occasion to be negligible axial compression on the heat source, the maximum shearing stress $\bar{\tau}_{max} = -\bar{\sigma}_{\theta\theta\ max}/2$ occurs at the center of the heat source. This shearing stress is larger over 1.2 times than the maximum tensile stress at the outer edge of the disk. Therefore this causes the first fracture. The second fracture will occur by the tensile stress at the outer edge adjacenting to the heat source. Absolute values of these maximum stresses are changed of cause by the conditions of a/R, e/R and heat transfer of the disk. Heating quantity Q_0 at the heat source can be converted to PV-value through the friction coefficient f as follows:

$$Q_0 = S_1 f PV/j \tag{2}$$

where j is a conversion factor such as 0.102 kg·m/W·S. Since Q_0 in Eq. (1) is replaced by a function of PV-value, the critical PV-values corresponding to the first fracture at the center of blister and the second fracture at the adjacent edge of the ring are expressed as follows:

$$[PV]_0 = \frac{K_{IC} k S_3 (1-\nu) j}{\bar{\tau}_{max} E\alpha S_1 S_2 f(b/2)\sqrt{\pi c}} \tag{3}$$

$$[PV]_1 = \frac{\sigma_t k(1-\nu)j}{\bar{\sigma}_{\theta\theta max} E\alpha S_1 f(b/2)} \quad (4)$$

where S_1, S_2 and S_3 are a local heating concentration factor, a shape factor in stress intensity factor for a penny shape crack of the diameter 2C and the ratio between mode I and II fracture toughnesses K_{IIC}/K_{IC} of materials, respectively. Material properties in Eqs. (3) and (4) are made into a bundle of the thermal shock fracture toughness $\nabla = K_{IC}k/E\alpha$ and the thermal shock resistance $\Delta = \sigma_t k/E\alpha$, respectively. Therefore, we have ,

$$[PV]_0 = \frac{\nabla S_3(1-\nu)j}{\bar{\tau}_{max} S_1 S_2 f(b/2)\sqrt{\pi c}} \quad (5)$$

$$[PV]_1 = \frac{\Delta(1-\nu)j}{\bar{\sigma}_{\theta\theta max} S_1 f(b/2)} \quad (6)$$

A pair of the critical PV-values of the mechanical seal are almost evaluated by determinations of ∇ and Δ of carbon.

Table 1 shows the conditions of eleven kinds of carbon specimens. The disk specimens used in the thermal shock testings are 2R = 30 mm and h = 3 mm. The ratios of a/R and c/R are 0.3 together.

Table 1. Conditions of carbon specimens for mechanical seal.

Specimen	Filler	Heat treat	Impregnation
H-1	pitch coke-graphite	1000°C	—
H-2	pitch coke-graphite	•	furan
H-3	pitch coke graphite	•	pitch epoxy
H-4	soot-graphite	•	—
H-5	soot-gaphite	•	furan
H-6	soot-graphite	•	pitch, phenol, polyamid imide
H-7	pitch coke	•	—
H-8	pitch coke	•	furan
H-9	pitch coke	1000°C	phenol
H-10	(pitch carbon, mesophase)	3000°C	—
H-11	(pitch carbon, mesophase)	3000°C	—

Table 2 shows the measured values of ∇ and Δ for all specimens. The critical PV-values were

Table 2. Experiment results and the deduced PV-values.

Specimen	∇(W/mm$^{\frac{1}{2}}$)	Δ(W/mm)	$[PV]_0$ (MPa m/s)	$[PV]_1$ (MPa m/s)
H-1	13.3	5.86	19.5	3.52
2	9.0	2.93	13.2	1.76
3	10.5	5.75	15.4	3.45
4	10.0	8.57	14.7	5.14
5	6.8	2.79	10.0	1.67
6	7.1	2.43	10.4	1.46
7	7.9	3.82	11.6	2.29
8	7.1	3.07	10.4	1.84
9	7.9	3.14	11.6	1.88
10	9.0	8.25	41.8	4.95
11	14.1	23.5	65.5	14.1

calculated from ∇ and Δ assuming as $S_1 = 100$, $S_2 = 0.707$, $S_3 = 1.2$, $\nu = 0.2$, $f = 1/3$, b = 5 mm, c = 0.05 mm for H-1 through H-9 and C = 0.005 mm for H-10 and H-11.

The practical examinations of carbon were performed using a mechanical seal testing apparatus in the conditions in Table 3. Table 4 shows results of the wear, leakage and the degree of failure on the sliding face of carbon rings as the mechanical seal. H-1, H-4 and H-7 were, however, excepted for porous basic materials.

Table 3 Testing condition by the mechanical seal testing apparatus.

Shaft diameter	40 mm
Rev. speed	3000 rpm
Oil pressure	0.68 MPa
Spring pressure	0.10 MPa
Surface pressure	0.94 MPa
[PV] value	7.06 MPa·m/s
Sealing liquid	C-heavy oil*
Counter face ring	Tungsten carbide
Testing time	30min, on — 60min, off
Cycle	100 cycles

*12 cSt (110°C)

Table 4. Experimental results of carbon rings of mechanical seal.

Specimen	Wear (μm)	Leakage (ml)	Failure*
H-1	—	—	—
H-2	4	24	4
H-3	6.5	1	1
H-4	—	—	—
H-5	10	45	5
H-6	10	5	2
H-7	—	—	—
H-8	4.5	6	3
H-9	26	38	5
H-10	4	6	1
H-11	8.5	1	1

*Blistering, pitting and hair cracking. A smaller number is better in the fivesteps evaluation.

These data were evaluated by averaging of four sets of mechanical seal. A measure of blistering and cracking was found for all rings, excepting H-10 and H-11 which were not observed blister. Values of $[PV]_0$ were calculated higher than the actual examination level of PV = 72 kgm/cm^{2}S (= 7.06 MPa m/s). But values of $[PV]_1$ are lower except H-11. Therefore according to the account by the local thermal stress simulation, the blistering is difficult to occur, but the cracking is easy to occur. In above discussion, influences of contact stress by friction and crack propagation by internal pressure for void were not included. But the orders of $[PV]_0$ an $[PV]_1$ - values correspond fairly to the experimental results on the whole.

References:

1) S. Sato, J. Aizawa, et al., 15th Biennial Conf. Corbon (1981), 327.
2) E. Mayer, Axiale Gleitringdichtungen, VDI-Verlag, (1970).
3) A.I.Golubiev, Fifth Inter, Conf. Fluid Sealing, (1979).
4) S. Sato, et al., Carbon, 16 (1978), 103.
5) S. Sato, et al., Carbon, 13 (1975), 309.
6) Y. Takeuchi, et al., Trans. JSME, 48A (1982), 747.