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Relation between Area of Opening and Range of Splash of Testing Fluid during Hydro Testing of Knife Gate Valve

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ABSTRACT

Determination of relations between various variables is necessary while designing any experiment. Various methods may be employed depending on the availability of resources at the experimental setup. However, while the experiment is being designed, it is equally important that the same is backed by theoretical formulae. If not derived or proved already, new ones can definitely be derived using first principles. In this study, a relation between the area of opening and range of splash shall be derived. The aim of this relation shall be to get a basic comprehension of the variation in parameters in relation to the range of splash of testing fluid. The concepts of range of splash and area of opening shall be reported at the initial stage. The area of opening shall then be determined using the method of integration considering variables involved in the formulation. On obtaining an expression, a relation between the area of opening and the range of splash shall be derived. Towards the end a conclusion shall be drawn reporting the proportional relations between the variables.

KEYWORDS: *Range, area, splash, hydro, testing*

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A. Introduction to Knife Gate Valves

Knife gate valves belong to the family of block valves which may also be known as on-off valves. These valves are primarily used in demanding applications like sludge, slurry, pulp, paper and so on where the working fluids are relatively thicker and need to be cut through with the aid of a knife gate. These valves are available in metal seat and soft seat options according to the requirement of the application. Various types of actuations like manual, pneumatic, gear and motorized electrical modes make these valves one of the most versatile and sought after for the stated applications.

B. Range of splash of testing fluid

During hydro testing of Knife Gate Valves, after completion of the Shell test and the Seat test, there is another test that can be performed qualitatively to confirm the performance parameters. This test comprises of pressurizing the valve at the upstream and opening the gate under this pressurized condition.

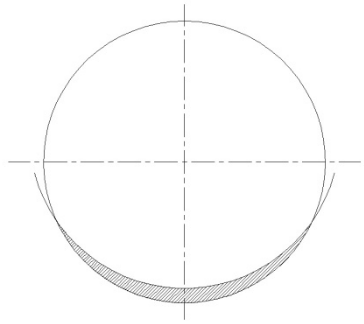
While doing so, at the instant when an opening is created by virtue of motion of the gate, there is a splash of testing fluid that can be observed to land at a certain distance. The horizontal distance covered by the splash is termed as the range of the splash. This paper shall try to establish a relation between the range of splash and the area of opening.

C. Area of opening creating a splash

Area of opening refers to the geometrical area opening responsible for the flow. In case of Knife Gate Valves, since the bore and gate have circular edges, the area is completely bounded by regular curves which are arcs. This makes it easier to evaluate the area as the equations of arcs are quite handy during the process of finding the area.

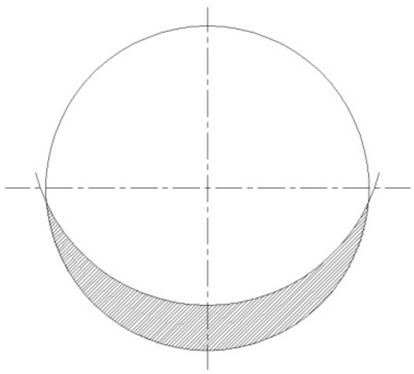
Following figures indicate the generation of flow areas at different degree or percentage of opening of the gate. The origin shall be considered as the reference and the same shall be coinciding with the bore center of the valve. Every figure comprises of a circle indicating the valve bore and an arc indicating the gate edge. The shaded area is the topic of interest in this interest.

The first consideration is as follows.



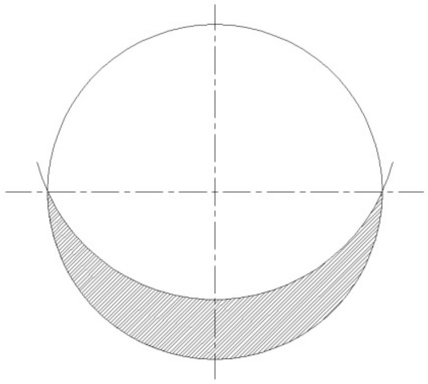
The figure depicts minimum percentage of opening and the area of flow generated thereby. The points of intersection of the two curves are distinct, do not lie on any axes and their intercepts form the boundaries or limits of integration while determining the flow area of opening. The shaded area can be determined by finding the difference between the area enclosed by the semi circle and the curve with respect o the abscissa between the limits. Since both the areas are on the same side of the abscissa, modulus of the area may or may not be considered while adding the same.

The second consideration is as follows



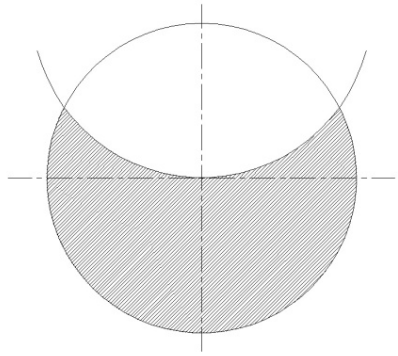
The figure depicts approximately a quarter of movement of gate opening and the area of flow generated thereby. The points of intersection of the two curves are distinct, do not lie on any axes and their intercepts form the boundaries or limits of integration while determining the flow area of opening. The shaded area can be determined by finding the difference between the area enclosed by the semi circle and the curve with respect o the abscissa between the limits. Since both the areas are on the same side of the abscissa, modulus of the area may or may not be considered while adding the same.

The third consideration is as follows



The figure depicts a point in time where the edges of the gate are collinear with the origin. The points of intersection of the two curves coincide with the abscissa thereby marking the boundaries or limits of integration to be the points on the circumference of the circle indicating the bore. The shaded area can be determined by finding the difference between the area enclosed by the semi circle and the curve with respect o the abscissa between the limits. Since both the areas are on the same side of the abscissa, modulus of the area may or may not be considered while adding the same.

The fourth consideration is as follows

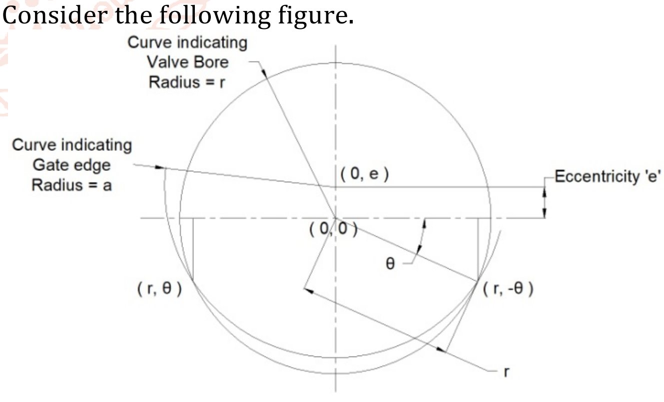


The figure depicts a point in time when the edge of the gate coincides with the origin. The points of intersection of the curves are distinct but in this case, the intercepts cannot be considered as the boundaries or limits of integration as certain definite or considerable area is lost while doing so. In this case and for further opening, while calculating the area, two different sets of integrals need to be considered based on the location of the point. For the third and fourth quadrants, the area is equal to half that of the bore. The areas in the first and second quadrant are symmetrical hence an arithmetic sum can be taken. A further division into two sets of areas, one bounded from the origin to the intercept corresponding to the point of intersection and the other from the intercept corresponding to the point of intersection to the radius of the circle need to be considered and calculated accordingly in order to obtain the total area.

Thus considering the scope of study, a little consideration will show that only the first figure would be applicable. Thus the remaining three figures shall be out of purview of this paper.

D. Determination of area of opening

Consider the following figure.



Let the valve bore be indicated by a circle of radius ‘r’ with its centre at the origin. Equation of the circle is given by.

$\mathbf{x^2 + y^2 = r^2}$ .....(1)

This circle shall indicate the flow area. The lowermost tip shall be the closing position and the uppermost tip shall be the open position.

Consider an arc indicating the gate edge of radius ‘a’ with its centre located at an eccentricity ‘e’ from the origin at a given instant. Since the arc is a part of the circle, the equation is given by.

$\mathbf{x^2 + (y - e)^2 = a^2}$ .....(2)

This equation can be written considering the circle to be at a centre other than origin, (0,e) in this case with a radius a units.

The area of opening can be determined by the method of integration by considering the intersection of these two curves.

Since two circles intersect at two points, symmetry can aid the ease of calculations and formulations. The points of intersection can be determined by solving the two equations. However while doing so theoretically, the arbitrary constants may not provide the coordinates of points of intersection. But during actual determination using the constants, the coordinates of points of intersection can directly be obtained.

In order to proceed with the derivation for the expression, the coordinates of points on intersection can be determined logically. It is clear from the figure that the point of intersection is at a polar radius of 'r' from the origin. This is applicable to any level of opening at the two curves would always intersect on the circumference of the circle indicating the bore.

Thus the coordinates of the point of intersection in polar system can be written as (r,-θ) and (r,θ). Here, the angle θ indicates the inclination of the radius with respect to the origin. As per the general convention, the angle considered in the clockwise sense shall be negative and that in the anticlockwise sense shall be positive. A little consideration will show that the angle of inclination is proportional to the eccentricity. This can aid in the numerical determination of the angle.

As an alternative, if Cartesian coordinates are considered, the same can be identified as (r.cosθ,-r.sinθ) and (-r.cosθ,-r.sinθ)

These points shall be the limits of integration in the expression.

Since the figure is symmetric about the ordinate, the ordinate shall be considered for evaluation of the integral and the abscissa shall be the reference axis.

From Equation (1),

$\mathbf{x^2 + y^2 = r^2}$

$\mathbf{y = \sqrt{r^2 - x^2}}$ .....(3)

From Equation (2),

$\mathbf{x^2 + (y - e)^2 = a^2}$

$\mathbf{x^2 + y^2 + e^2 - 2ey = a^2}$

$\mathbf{y = \sqrt{a^2 - x^2 - e^2 + 2ey}}$ .....(4)

The required area of opening is the difference between areas individually enclosed between the two curves within the limits defined by the points of intersection of the curves.

Area enclosed by the curve indicating the bore, abscissa between the points of intersection is given by.

$\mathbf{A_1 = 2\int_0^{r.\cos\theta} \sqrt{r^2 - x^2}\, dx}$ .....(5)

Area enclosed by the curve indicating the gate edge, abscissa between the points of intersection is given by.

$\mathbf{A_1 = 2\int_0^{r.\cos\theta} \sqrt{a^2 - x^2 - e^2 + 2ey}\, dx}$ .....(6)

The difference between these areas can provide the expression for the area of opening which is more or less always in a crescent shape.

Required area,

$\mathbf{A = 2\left(\int_0^{r.\cos\theta} \sqrt{r^2 - x^2} dx - \int_0^{r.\cos\theta} \sqrt{a^2 - x^2 - e^2 + 2ey}\, dx\right)}$.....(7)

Thus further solution of Equation (7) gives the area of opening of the valve at the required instant. The radii can are known and the eccentricity depends on the degree of opening.

Relation between area of opening and range of splash

In this section, a relation shall be derived relating the range of splash and the area of opening.

According to the Hydrostatic law, the Pressure 'P' can be expressed in terms of an equivalent head 'H'

P = ρ . g. H .....(8)

Where ρ = Density of flow media

g = Acceleration due to gravity

H = Height of fluid column i.e. head

On further simplification,

H = P / (ρ . g) .....(9)

Thus the head corresponding to the line pressure can be calculated.

For flow through orifices, corresponding to a head 'H', the velocity of flow through the orifice can be given by the following expression available in literature[1].

$\mathbf{V = \sqrt{2 . g. H}}$ .....(10)

The discharge of fluid through the opening of area A as calculated using Equation (7) and the flow velocity is given by.

Q = AV .....(11)

The hydraulic power available at the upstream is a product of the pressure and discharge.

Power, W = ρ . g . Q . H .....(12)

On rearranging the terms on both sides after substitution,

$\mathbf{V = \frac{W}{\rho . g . A . H}}$ .....(13)

Range of splash, [3]

$\mathbf{R = V. \cos\theta. t}$ .....(14)

Substituting Equation (13) in Equation (14),

$$\mathbf{R} = \frac{\mathbf{W}\,.\mathbf{cos\theta}\,.\mathbf{t}}{\boldsymbol{\rho}\,.\mathbf{g}\,.\mathbf{A}\,.\mathbf{H}} \quad .....(15)$$

This is the required expression that gives the relation between the area of opening and the range of splash.

As the hydraulic power increases, the range is said to increase proportional to the amount of fluid being discharged.

As the density of testing fluid increases, the range of splash decreases due to the tendency of the fluid to cover a shorter range on account of its inertia.

Range of splash and the area of flow are inversely proportional. At the instant of opening, there is an infinitesimal area of opening which can lead to the maximum range of splash. As the percentage of opening increases, the area also increases proportionately but the pressure reduces, thereby leading to an increase in the discharge. The properties of cohesiveness and fluid viscosity tend the splash to be generated with a shorter range.

Conclusion

Thus it can be concluded that considering the area of opening, the range of splash of testing fluid is directly proportional to the hydraulic power and the time interval while it is inversely proportional to the density of the fluid, area of opening and the hydrostatic head. Thus a relation has been established theoretically.

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