Development of Calculation Algorithm for ECCS Kinematic Shock

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1. Introduction

The void fraction of inverted U-pipes in front of SI(Safety Injection) pumps impact on the pipe system of ECCS(Emergency Core Cooling Systems). This phenomena is called as "Kinematic Shock". The purpose of this paper is to achieve the more exactly calculation when the kinematic shock is calculated by simplified equation. The behavior of the void packet of the ECCS pipes is illustrated by the simplified (other name is kinematic shock equation)[1,2]. The kinematic shock is defined as the depth of total length of void clusters in the pipes of ECCS when the void cluster is continually reached along the part of pipes in vertical direction. In this paper, the simplified equation is evaluated by comparing calculation error each other.].

2. Methodology

Some fundamental forms are introduced to illustrate the phenomena of kinematic shock.

2.1. Motion of Void Packet in Simplified equation

The movement of the void packet of ECCS pipes is illustrated from Newton Mechanics.
If the void packet is big, the air is similar to a falling object. Also, it have the kinetic energy equivalent to potential energy of hight H.
Here, the void packets experience the falling motion of gravity. Therefore, the falling velocity of void packet in ECCS pipe is followed below;

$$\frac{1}{2}mv^2 = mgH \qquad (1)$$

Where m is mass of falling void packet, v is velocity, g is gravity acceleration, H is vertical length of falling void packet. From Equation (1), the velocity of falling void packet is introduced as following;

$$V= \sqrt{2gH} \qquad (2)$$

The damage possibility of pumps located in front of the SI pump is specified by the depth of void package.
Using equation (1) and (2), a vertical separated flow frame enables the water to accelerate such that

$$U(H) = U_0 + \sqrt{2gH} \qquad (3)$$

The volumetric flow remains constant, hence

$$A_w(H) = \frac{Q_0}{U(H)} = \frac{A_0 U_0}{U(H)} \qquad (4)$$

Where $A_w(H)$ is the vertical cross section of water fall H or the vertical cross section of falling gas volume height H.

From Equation (4), equation (5) and equation (6) are achieved as following:

$$V_w = \int_0^H \frac{Q_0}{\sqrt{2gH}} dH = Q_0\sqrt{\frac{2H}{g}} \qquad (5)$$

$$H_1^2 - U_0\sqrt{\frac{2}{g}} H_1 - \frac{V_g}{A_0} + \left(\frac{\log(UQ_0A_0)}{gA_0}\right) = 0 \qquad (6)$$

2.3. Calculation and Error in Simplified Equation

In section 2.1, equation (5) and equation (6) are calculated by common integral method. From these results, we will find the more efficient calculation method.
To calculation equation (5), numerical quadrature method is used. In case of equation (6), finding root is calculated by approximation search method.
Numerical quadrature and approximation search are general methods in calculating integral and finding root.
Numerical quadrature method is carried out by Newton-Cotes form as following:

$$\int_{-h}^{h} f(x)dx = \frac{h}{2}(f_{-1} + 2f_0 + f_1) + \delta(h^3) \qquad (7)$$

Approximation search method is carried out by conditions as below:

$$f\left(x + \left(\frac{h}{2}\right)\right) \cdot f\left(x + \left(\frac{h}{2}\right)\right) < 0 \qquad (8)$$

$$f'\left(x + \left(\frac{h}{2}\right)\right) \cdot f'\left(x + \left(\frac{h}{2}\right)\right) > 0 \qquad (9)$$

here, term (8) is function value product and term(9) is function's differential value product.
To minimize the error of (7), (8) and (9), we use the Taylor's series.
From Taylor expansion, f(x) of (7) is changed to form (10) as below:

$$f(x) = f_0 + \frac{f_1 - f_{-1}}{2h}x + \frac{f_1 - 2f_0 + f_{-1}}{2h^2}x^2 + \delta(h^3) \qquad (10)$$

form (10) is used for integral calculation as below:

$$\int_{-h}^{h} f(x)dx = \frac{h}{3}(f_{-1} + 4f_0 + f_1) + \delta(h^5) \qquad (11)$$

Using form (11), more exactly form (12) is generated as below:

$$\int_{-h}^{h} f(x)dx = \frac{2h}{45}(7f_{-2} + 32f_1 + 12f_0 + 32f_1 + 7f_2) + \delta(h^7) \qquad (12)$$

In another hand, from terms (8) and (9), differential method is used to minimize error. Differential method is carried out by searching the convergence value under assumption of linear shape in the near of x0.
Differential method is introduced below:

$$x^{i+1} = x^i - \frac{f(x^i)}{f'(x^i)} \quad (13)$$

Here x^{i+1} is convergence value and the value is finding root.
Form (13) can be changed into form (14) to improve as below:

$$x^{i+1} = x^i - f(x^i)\frac{(x^i - x^{i-1})}{f(x^i) - f(x^{i-1})} \quad (14)$$

$$f(x^i) \cdot f(x^{i-1}) < 0 \quad (15)$$

Under the condition (15), x^{i+1} of form (14) is always finding root.
Form (7) , (11) and (12) are named as Newton-Cotes form, 5-th Taylor's expansion form, and 7-th Taylor's expansion form respectively.
Form (13) and (14) are named as differential root method and secant method respectively.
To calculate the equation (5), form (7) is used and the result is compared with form (11) and form (12). Also, to find the root of equation (6), form(8) is used and the result is compared with form (13) and form (14).
Numerical calculations is achieved by using "Object Pascal (Delphi V 6.0) and Free Pascal Compiler.

3. Result and Discussion

3.1. Numerical Quadrature in Integral Calculation

Table1 shows the calculation error of equation (5) in the case of void weight for ECCS kinematic shock.

From here, the results of complex form (12) can make the more exact value. We thought that higher order equation is more exact than lower order equation, but these results are not in the conception. The reason is because the higher order equation has the big oscillation term.

Table1. Comparison of error terms in calculation of equation (5)

N	h	Form (7)	Form(11)	Form(12)
4	0.250000	-0.008940	-0.000037	-0.000001
8	0.125000	-0.002237	0.000002	0.000000
16	0.062500	-0.000559	0.000000	0.000000
32	0.031250	-0.000140	0.000000	0.000000
64	0.015625	-0.000035	0.000000	0.000000
128	0.007812	-0.000008	0.000000	0.000000

3.2. Finding Root in Equation (6).

In order to verify this work, form (13) and (14) are compared each other in Table 2. In this case, the search gap of function should be suitable to calculate the equation (6). If not that, in case of multiple root equation, the probability of not finding the equation root, because of too big search gap. Therefore, when the fore calculation and the next calculation have smaller value than the standard value, the calculation process is finished.

Table2. Comparison of error terms in finding roots of equation (6)

repeat	Form (8)	Form(13)	Form(14)
0	1.236076	1.236076	1.236076
1	0.736068	-0.763932	-1.430599
2	0.236068	-0.097265	0.378925
3	-0.263932	-0.002027	0.098137
4	-0.013932	-0.000001	-0.009308
5	0.111068	0.000000	0.000008
6	-0.013932	0.000000	0.000000
7	0.020687	0.000000	0.000000
8	-0.001024	0.000000	0.000000
9	0.000111	0.000000	0.000000
10	-0.000095	0.000000	0.000000
11	0.000012	0.000000	0.000000
12	0.000009	0.000000	0.000000
33	0.000001	0.00000	0.00000

4. Conclusions

The more exact methods of calculating the depth of the kinematic shock in ECCS is achieved. The error of kinematic shock calculation is strongly depended on the calculation search gap and the order of Taylor's expansion. From this study, to select the suitable search gap and the suitable calculation order, differential root method, secant method, and Taylor's expansion form are compared one another. The comparison of the calculation error shows that this study is very efficient to minimize the error term.

APPENDIX

From equation (4) in chapter 2.1, assume the water thickness x would be approximated as a linear function such that the flow area could be represented as below;

$$A_w(H) = \frac{\pi}{4} Dx(H) \quad (A1)$$

From equation (4) and (A1), as the water accelerates, the thickness change is below;

$$x(H) = \frac{4Q_0}{\pi DU} = \frac{4Q_0}{\pi D(U_0 + \sqrt{2gH})} \quad (A2)$$

Through the equation (A1) and the equation(A2), it is founded that the water volume is bounded by the bottom of the high point pipe and the location where the water jet plunges into the water filled down-comer where the jet entrains air from the gas volume.
The pattern is below;

$$V_w = \int_0^H \frac{\pi}{4} Dx(H)dH = \int_0^H \frac{Q_0}{U_0 + \sqrt{2gH}} dH \quad (A3)$$

Here, in order to simplify, letting the term of liquid motion (U_0) zero. Or Assume that U_0 is smaller than $\sqrt{2gH}$. Then, this equation is written as;

$$V_w = \int_0^H \frac{Q_0}{\sqrt{2gH}} dH = Q_0\sqrt{\frac{2H}{g}} \quad \text{(A4)}$$

From equation (A3) and (A4), the gas volume is calculated as like equation (A5) and modified as like equation (A6).

$$V_g = A_0 H - V_w \quad \text{(A5)}$$

$$H = \frac{(V_g + V_w)}{A_0} \quad \text{(A6)}$$

If equation (A4) is inserted into equation(A5), equation(A6) is rewritten as;

$$H = \frac{\left(V_g + Q_0\sqrt{\frac{2H}{g}}\right)}{A_0} \quad \text{(A7)}$$

Letting $H_1 = \sqrt{H}$, equation (A7) is modified into secondary equation (A8) and the solution is written (A9).

$$H_1^2 - U_0\sqrt{\frac{2}{g}} H_1 - \frac{V_g}{A_0} = 0 \quad \text{(A8)}$$

$$H_1 = \frac{1}{2}\left[U_0\sqrt{\frac{2}{g}} + \left(\frac{2U_0^2}{g} + \frac{4V_g}{A_0}\right)^{1/2}\right] \quad \text{(A9)}$$

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Here, equation (A9) is simplified form.

REFERENCES

[1] TSTF 10-05, Transmittal of TSTF-523, Revision 0. “Generic Letter 2008-01, Managing Gas Accumulation”, June 29, 2010.

[2] Perdu Test Report, “Simplified Equation for Gas Transport To Pumps”, January 21, 2010, NEI Workshop.