PIPE WHIP ANALYSIS FOR NUCLEAR REACTOR APPLICATIONS

N. BISCONTI, L. LAZZERI, P.P. STRONA

SAIGE, Società di Architettura Industriale per gli Impianti di Generazione di Energia, Genova, Italy

SUMMARY

AEC Regulatory guides as well as similar regulatory practice in other countries (e.g. Italy) imposes that the consequences of the uncontrolled movement of a pipe after a LOCA accident should be considered. The procedure envisaged by the authors is as follows:

- Criteria to determine breakage locations based on pressure, stress levels, etc., are available and are briefly discussed;
- The various possible ways of limiting the damage due to the uncontrolled movement of the pipe are reviewed (damage envelope, restraints, dampers, etc.)

If a restraint solution is necessary a computation of the forces resulting in each postulated breakage is performed by means of the GETTO program, which uses the simplified theory due to Moody.

A preliminary analysis of the type, location and characteristics of the restraints is performed by means of the same GETTO code which uses a very simple and rough energy balance between the energy due to the jet force and the energy absorbed by the restraints (correction parameters are introduced coming from practice).

A final appraisal of the design is performed by means of the FRUSTA code, which entirely simulates the pipe and restraint behaviours during the transitory (see also the companion paper F 5/6).

Typical examples for some cases are presented and discussed, with particular reference to the following points:

- (a) discussion of the allowable values for pipe and restraint;
- (b) influence of some typical parameters.

1. Introduction

AEC Regulatory guide N° 1.46 "Protection Against Pipe Whip Inside Containment" (1) and similar documents for piping outside containment imposes the necessity of a detailed analysis in order to show that the movements of the pipe accelerated by the fluid outcoming from a postulated breakage will not cause further damage to ECCS, to other protections or to other piping. A similar attitude has been assumed by other National Safety Authorities such as CNEN in Italy.

SAIGE has decided to face the problem by means of a group of computer programs in order to:

- a) compute the forces applied to the piping

- b) to develop a tentative restraint distribution around the critical points in the piping, if a "restraint solution" is necessary

- c) to reevaluate the preliminary results of point b by means of a more refined computer code

Three computer programs are available in order to solve each of the mentioned problems, they are:

GETTO 1, GETTO2 and FRUSTA

The type of analysis performed by SAIGE is best illustrated by the following points:

- 1) Decide where breakage must be considered for each line
- 2) Computer the forces applied to the piping for each postulated breakage
- 3) Decide whether a solution based on restraints or similar devices (dampers) is necessary
- 4) If a "restraint solution" is necessary, derive a tentative design, which gives number and type of restraint for each critical location
- 5) In a given number of sections (the most critical) perform an analysis of the tentative design by means of a more sophisticated computer code
- 6) Evaluate the results, comparing actual values of forces on restraints and strains in the pipe with the allowable values

Each point will be briefly described in the following paragraphs:

2. Breakage locations

The choice of the locations where a breakage must be considered is to be made on the basis of the relative probability of occurrence of the phenomenon; fracture mechanics studies indicate that such sudden breakage is to be accompanied by fairly large size cracks, which could be detected by means of standard inspections methods.

Anyhow if such an accident has to be considered, fracture mechanics studies would indicate that the crack would develop in high stresses regions; such an attitude has been assumed by Regulatory Guide 1.46 (1), where basically for a class I pipe, a break is postulated wherever either the secondary stress exceeds 2.0 (or 2.4 austenitic steels) S_m or the usage factor exceeds 0.1.

A slightly different attitude has been used in the past in Italy, where a break is postulated in every point, where an elbow, a branch, a Tee connection is present (an unfavourable combinations of stress raisers and fabrication difficulties is then assumed to possibly generate a breakage)

3. Forces computations

The theory of Moody (3), as developped in ref.2 has been used to write "Getto1"program; basically the jet force is assumed as given by

$$(3.1) \quad F_j = c P A$$

where F_j = jet force c = coefficient function of time, geometry, flow areas
 P = pressure upstream of the break and friction
 A = outflow area

Conservatively the outflow area is assumed as equal to the pipe area (provided no other restriction exists in the line) (so the actual break area is "not controlling" and can assume any value). The coefficient c is a function of time, geometry, flow areas and friction inside the pipe (see ref. 2, 3, 4).

For a circumferential break (its axis is parallel to the pipe axis) formula 3.1 is used, for a longitudinal break the sum of the forces upstream and downstream is assumed (so the force is the sum of the forces due to the two circumferential breaks)

$$(3.2) \quad F_j = \left(\sum_{i=1}^2 C_i P A \right) C_s$$

where C_s is a coefficient, which takes care of the splashing beneficial effect (its value has been assumed conservatively in 0.9 + 1.0 region).

In fig.1 a typical line is presented with indications of pressure, geometry and fabrication particulars. In table I the results are given for a longitudinal break and for the two circumferential breaks.

4. Solution analysis

Regulatory Guide 1.46 provides criteria to decide whether a restraint (or dampers solution) is necessary; no protection is required if any of the following condition is fulfilled:

- a) the pipe is physically separated from any other component necessary for safety
- b) no damage will result to any safety related component, whichever is the movement of the pipe a hinge is postulated at each end)
- c) the energy of the pipe (due to its size or pressure) is not enough to cause damages to structures or system important for the safety

If these conditions are not fulfilled a protection is necessary: either dampers (both hydrodynamical or mechanical) or restraints (see ref.(3,5) for typical concepts) may be used.

Basically the desirable characteristics of a restraints system should be:

- a) no force or restraining action is given during the normal life of the plant: thermal movements are permitted as well as any other "slow movement"
- b) a large amount of energy is dissipated in the restraining units, while the force is as low as possible so that the deceleration phase will not be too heavy for the pipe
- c) a modular solution is desirable for unification purposes
- d) dismantling of the restraining units has to be possible in order to allow in service inspections of the pipe
- e) maintenance (if necessary) should be easily performed

5. Preliminary analysis

If a restraining solution (whose units have a behaviour, which can be modelled as in fig.2: a two sides linear support with initial gap) is used a preliminary analysis may be performed by means of the Getto 2 code, which directly uses the output of Getto 1. The restraints are given to the program by specifying the following data:

- a) by which breakage every restraint is loaded
- b) assuming that each restraint is formed by a number of moduli having the same properties, such properties are given (initial clearance, stiffnesses, load capability etc.)
- c) assuming that the reaction of the restraints will be dependent on the direction of the impact, the direction (frontal or lateral) will be specified.

An energy balance is performed by the program under the assumption that nearly all the energy of the jet is taken by the restraints (some corrective factors coming from practice are used) and the number of modular units is consequently computed. For each restraint different loadings are possible, if various breaks are postulated, the program computes the number of moduli for each load and registers the highest one (design case).

A typical example is presented for the case given in fig.1 in table II.

6. Final solution appraisal

After the preliminary analysis the final appraisal of the solution is performed by means of the more sophisticated FRUSTA program (6, 7, 8), which allows a rather exact modelling of the main features of the pipe and restraint. For a more exact description see the companion paper F5/6, this same conference.

In the present paper only a typical example of a computation is given see fig. 2.

A discussion of the main parameters influence in the problem was given in ref.6 and has been confirmed by further experience; anyhow it is evident that:

- a) the restraint should be located as near as possible the break location in order to reduce the lever arm of the applied jet force

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b) the initial gap between pipe and restraint should be kept as low as possible in order to reduce the Kinetic energy of the pipe prior the contact

c) The stiffness of the restraints is a very critical parameter

An increase results in an increase of the deceleration force in the pipe with possible increase in the strain in the pipe at the location where the impact with the restraint takes place. On the other end if the stiffness is too low, excessive strain in the restraints units may take place. So an optimum solution exists for each problem.

7. Limitation of strains and forces

The maximum force on the restraining unit will be based essentially on its maximum load capability and will depend on the type which is used in the design.

For hydraulic units values of maximum load capability as high as one million pounds or more have been reported by the manufacturers (allowable values should be some fraction of it). For mechanical units, in which the energy must be absorbed as a strain plastic energy, the maximum load capability of the restraining unit should be based on the allowable values of the strain. For stainless steel units allowable values of the average strain as high as 25% have been reported; such being the case, for 1.25" V bar the load capability is in the range of roughly 150000 pounds.

For the pipe the limitation of load capability should be based either on the maximum strain in the pipe or on the maximum capability of the pipe before a statically indeterminate structure is formed through the developping of a certain number of hinges. If the limitation on the pipe strain is kept then the ovalization (Brazier) phenomenon should be kept in mind (9), experimental data are available (even if they have been generally obtained for pipes much thinner than the ones in the case of nuclear pipes) and the critical strain is:

$$(7.1) \epsilon_{cr} = 0.6 \gamma t/R$$

where t/R = thickness to ratio (generally in the 0.1 range)

γ = gradient factor (generally in the 1.0 + 2.0 range)

Obviously the pipe has large energy capability even after ovalization is reached, really a flat moment-rotation phase exists, and then an instability region follows, where an increase in the rotation causes a decrease in the moment.

However it should be kept in mind that even after complete flattening in a given section energy capability still exists in the pipe, so the second criterion seems to have a much more logical base than the first one.

References:

- (1) Regulatory guide 1.4/6 "Protection against pipe whip inside containment"
- (2) Esswein et al "Systems criteria for protection against pipe break for the MarkIII Containment" NEDO 10990 Sept.1973
- (3) Moody "Prediction blowdown thrust and jets forces" ASME paper 69-HT-31, 1969
- (4) "Analisi del colpo di frusta "Programma Getto ed 2" Internal SAIGE Report 0028MX00004
- (5) Palusamy Patrick Cloud " Dynamic analysis of non linear pipe whip restraints" Nuclear Engineering and design Vol. 31 (1974) 1
- (6) Dini Lazzeri "An analysis of the dynamic elastoplastic behaviour of a pipe during the pipe whip accident" paper F5/4, 2nd SMIRT Conference, Berlin 1973
- (7) Dini Lazzeri "Descrizione del programma di calcolo FRUSTA" CNEN Report RT/PROT(73)15
- (8) Dini Lazzeri "Modelling techniques for pipe whip analysis" paper F5/6 3rd SMIRT Conference, London 1975
- (9) Gerard "Handbook of structural stability" NCA-TN-3783

press. 60 atm

ϕ pipe 60 cm

Rest. type 1

Fig. 1

Fig. 2

TABLE 1
"JET FORCES"

Break	Code	F_1	t_1	F_2	t_2	F_3
		t	msec	t	msec	t
1	CV	148	0	103	0	186
	CT	148	16	103	104	115
	L	266	1	186	104	271
2	CV	148	16	103	32	144
	CT	148	26	103	72	115
	L	266	1	186	72	233
3	CV	148	26	103	84	120
	CT	148	10	103	20	115
	L	266	1	186	84	212
4	CV	148	10	103	104	114
	CT	148	0	103	0	115
	L	266	1	186	104	205
7	CV	148	0	103	0	115
	CT	148	6	103	24	154
	L	266	1	186	24	242
8	CV	148	6	103	12	115
	CT	148	6	103	12	170
	L	266	1	186	12	256

CV Circumferential breakage Vessel Side

Code CT Circumferential breakage Turbine Side

L Longitudinal breakage

F_1 force before time t_1

F_2 force after time t_1 before time t_2

F_3 force after time t_2

TABLE 2.1
Restraint Conditions

N	Circ.		Long.	
	Ves.Side	Turb.Side		
1	-	2F	-	-
2	-	4F	1L	2L
3	1F	8F	3L	4L
4	3F	8F	5L	6L
7	3F	8F	5L	6L
8	3F	-	7L	8L

TABLE 2.2
Restraint tentative dimensioning

<u>Rest.</u>	N.mod. units	Critical break
1	6	2
2	6	2
3	5	3
4	5	3
5	6	7
6	6	7
7	6	8
8	6	8

TABLE 3

Detailed analysis of example in fig. 2

time step	9.13×10^{-5} msec
impact time on restraint node 4	31.4 msec
impact time on restraint node 2	32.4 msec
conventional stop at	40 msec
displacement of node 3	64.7 cm
displacement of node 2	57.8 cm
displacement of node 4	58.8 cm
max force on restraint 2	335 t.
max force on restraint 4	343 t.
allowable force on restraint	413 t.
energy absorbed by pipe	44.80 tm
energy absorbed by restraints	61.0 tm
max strain on pipe on restraint 2	1.63 %
solution time on IBM 370/145	53 sec

NOTE: The present analysis refers to the case "longitudinal break on node 2" of fig. 1, the forces were derived from table 1.

A preliminary configuration from table 2.2 was assumed.

An extremely rough model was used as precedent experience shows that a limited number of nodes is generally satisfactory.