SIMULATION AND ANALYSIS OF A MAIN STEAM LINE TRANSIENT WITH ISOLATION VALVES CLOSURE AND SUBSEQUENT PIPE BREAK

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1. Introduction

In this paper, numerical simulation and analysis of a real main steam lines transient at the coal fired, 300 MWe Thermal Power Plant Drmno are presented. Main events of the transient were the closure of isolation valves in front of the high pressure turbine, the opening of by-pass lines, and subsequent pipe break in front of one isolation valve (Studovic et al., 1991). Intensive pressure waves were generated and they propagated through the pipe network of the steam lines, causing high fluid dynamic forces on the structure.

The transient has been simulated by the computer code TEA-01, based on the Method of Characteristics and verified for various fast thermal-hydraulic transients (Stevanovic, 1986, Stevanovic and Studovic, 1990). Simulations and analysis have had specific tasks: to estimate the pressure pulse load caused by the action of the turbine isolation valves and the by-pass system, and to predict the intensity of blowdown force in the broken steam line. Several main steam line boundary conditions have been modeled and verified. Numerical results are compared with plant data logger records. Simulations have been performed for various scenarios in order to investigate the plant behavior sensitivity to the boundary conditions. Pressure wave propagation and the influence of the boundary conditions on this process is described, as well as fluid dynamic forces on the steam line in the vicinity of the pipe break.

Although the investigated processes took place at a coal-fired thermal power plant, the methods and obtained results are applicable to nuclear power plant safety. The pressure wave propagations, reflections and superpositions, the geometry of the pipelines and their volumes, and the action of the isolation valves and by-pass system are similar for nuclear and conventional thermal power plant.

The Method Of Characteristics has been used for the simulation of fast thermal-hydraulic transients, (Stoop et al., 1985, Choi, 1983), because it gives potentially the most accurate solutions, especially for the one-phase compressible fluid flows, and it enables proper modeling of boundary conditions (Shin and Wiederman, 1981). Also, the RELAP and RETRAN codes are often used for the calculation of thermal hydraulic transients. The simulation of the fast thermal hydraulic transient by RELAP 4/5 code was compared with the simulation of the CHARME computer code, based on the method of characteristics, in the paper (Stoop et. al., 1985b). The comparison had shown that the RELAP code is less suited for the calculation of processes where the shock waves and the propagation of distinct liquid-gas boundaries must be considered. The steam line break transient was analyzed with the RETRAN code, (Neises and Garett, 1991).

2. Computer Code TEA-01

The code TEA-01 has been developed for the simulation and analysis of fast thermal-hydraulic transients in Thermal Power Systems (components of Thermal and Nuclear Power Plants, Steam Boilers, District Heating Piping Networks, etc.) during various disturbances and operational conditions. The characteristics of thermal-hydraulic processes and systems' flow networks have determined the following features of the TEA-01 code:

- one and two-phase flows of water and steam are modeled, where the two-phase flow is described by a homogeneous model;
- evaporation/condensation and propagation of phase change fronts are included in an equilibrium model (the extension towards nonequilibrium phase change is possible);
- hydraulic forces by which the fluid acts on a piping are modeled;
- a system's network can be easily defined by simple input parameters.

One-dimensional transient flow of homogeneous fluid, in a flow channel of constant area is described by mass, momentum and energy balance equations:

$$\frac{D\rho}{Dt} + \rho \frac{\partial u}{\partial x} = 0, \tag{1}$$

$$\frac{Du}{Dt} + \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{fu|u|}{2D_H} + g\sin\theta = 0, \tag{2}$$

$$\frac{Dh}{Dt} - \frac{1}{\rho}\frac{Dp}{Dt} - \frac{fu|u|^2}{2D_H} - \frac{\dot{q}}{\rho} = 0 . \tag{3}$$

This system of equations is solved for the appropriate initial and boundary conditions by the Method of Characteristics.

The steam boiler is represented by a point model, which comprises an equilibrium two-phase mixture, heat source, feedwater inflow and steam outflow. The model is based on the mass and energy balance equations:

$$\frac{dM}{dt} = \sum \dot{m}_{in} - \sum \dot{m}_{out}, \tag{4}$$

$$\frac{dH}{dt} = \dot{Q} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out} + V\frac{dp}{dt}, \tag{5}$$

and equations of state and functional characteristics of the system (feedwater inflow and steam boiler heat power). These equations are solved by the Runge-Kutta method for the known initial conditions and for the time interval which consists of several time-steps of integration performed for the steam pipelines by the Method of Characteristics.

In order to simulate the complex pipe networks and various transient scenarios, code TEA-01 comprises several models of boundary conditions: a subcritical or critical leakage from a pipe, a closed end of a pipe, a pipe in a junction with a tank, a junction of two or more pipes with or without pumps or heat exchangers, a valve in a pipe, flow parameters determined as functions of time. The TEA-01 code has been verified on the various physical tests data which are available in the literature (Stevanovic, 1987, Stevanovic and Studovic, 1990, Studovic and Stevanovic, 1985).

The algorithm of the TEA-01 code is given in Fig.1.

Code TEA-01 is equipped with the graphics software. It is designed in order to animate the time-dependent propagation of flow parameters along pipelines or the time-change of flow parameters and transient fluid dynamic forces at specific locations within the network. Graphics are displayed on the PC's screen during the computer simulation, and they can be printed.

3. Numerical Simulation of the Main Steam Line Transient

The main steam line break transient occurred at the coal fired, 300 MWe Thermal Power Plant Drmno-Yugoslavia, in april 1991. The accident resulted in the rupture of the main steam line at the junction with the high pressure turbine isolation valve (double-ended guillotine), and subsequent blowdown of the steam boiler. The main events of the transient were consequently:

- the plant was on constant power;
- the high pressure turbine isolation valves were closed by the operators because of the small leakage on the main steam line, which was audible;
- after 20 s from the turbine isolation valve closure, rupture of the steam line occurred in front of the isolation valve;
- sceam passed from the boiler through the break in the main steam line to the turbine building.

In order to derive the sensitivity of the system to the isolation valve action, and the by-pass system's action, as well as to obtain the most conservative case of the possible system parameters change during transients, various modeling scenarios were prepared, for the following time intervals (Studovic et al., 1991):

- less then one second in order to simulate the pressure wave propagation and transient fluid dynamic forces during and after the isolation valve closure;
- a few seconds in order to predict the pressure in the steam lines and steam boiler after the isolation valves closure; and
- a few minutes in order to simulate the system's blowdown after the pipe break.

The main goal of the computer simulation was to determine maximum pressures and fluid dynamic forces which were loading on to the main steam pipeline in the vicinity of the break, and to evaluate whether these loads had been able to cause the break.

3-1. Pressure wave propagation and fluid dynamic forces during isolation valve closure - time interval less than one second

The main steam pipeline was modeled in all details with 16 pipes including various Y and T junctions, isolation valves, outflow through the by-pass line, and junction with the steam boiler. The system nodalization is shown in Fig. 2. The once-through steam boiler is represented on its water side as a volume filled with two-phase steam and water mixture in equilibrium conditions, determined by the average pressure (which corresponds to the pressure at the exit from the evaporating section - the separator).

Several scenarios have been prepared. The duration of the isolation valves closure is varied from 0.03 s to 0.2 s, and the by-pass valve starts to open at different times (0.1 s and 0.2 s after the transient beginning), or it remains closed. Initial total steam flow is 260 kg/s and the steam temperature is 540°C.

Typical steam pressure distribution is shown in Fig. 3 for different times and along the path which is formed by the pipes 15, 13, 12, 3 and 5 from Fig. 2.

The transient fluid dynamic forces are calculated for the parts of the pipeline where the rupture took place, figure 4, during the main isolation valves closure. Lengths of the pipes are: L_1=2.4m, L_2=3.6m, L_3=5.5m, and diameter is D=0.252m.

3-2. Pressure change in the main steam line after the isolation valve closure - a time period of a few seconds

In order to predict the maximum pressure in the period after the isolation valve closure and up to the pipe break, thermal-hydraulic processes are modeled in the main steam line and in the steam boiler during the period of 20 s. The system is nodalized, as is shown in Fig. 2, and two scenarios have been performed. According to the first, the isolation valves close for 0.2 s and after that by-pass starts to open. In the second scenarios isolation valves also close for 0.2 s, but the by-pass stays closed.

Fig. 5 shows the simulated and measured pressure at various points within the system for the first scenario. The pressure reaches the average value - 185 bar in the whole considered system. There are no pressure waves propagations. The calculated results are in agreement with the measured values (recorded by the process computer). The sudden pressure decrease occurs at 20 s because of the pipe rupture.

In the simulation with the second scenario, steam boiler heat power and feedwater inflow are the same as for the first scenario but the by-pass line is not opened. For that reason the pressure increases from 168 bar to 203 bar for 20 s. The pressure in the steam line is approximately the same as in the steam boiler.

3-3. Decompression after the pipe rupture - period of a few minutes

An instantaneous 100% pipe rupture in front of the isolation valve is assumed at 0 s. The critical outflow is reached at the pipe break. Fig.6 shows the computed and measured pressures during the blowdown at the various points of the system. The pressure immediately falls to 40 bars at the break , and this pressure continues to fall to 10 bar after 200 s. During the first 500 s the steam is mainly generated because of the adiabatic evaporation in the steam boiler, and 80% of the initial water and steam mass in the boiler is discharged into the turbine hall.

It is predicted that the fluid reactive force at the break, in front of the isolation valve, reaches the value of 10^6 N immediately after the rupture. This high value of the reactive force led to 1 m pipe movement in the direction of the force at the Plant Drmno.

4. Conclusion

The simulation and analysis of the main steam line transient with the isolation valves closure and subsequent pipe break are shown. The results could be used as the input data for the stress analysis of the pipeline. Also, measured and calculated data of steam leakage were used as input data for a determination of temperature and pressure history in the turbine hall during blowdown (Studovic et al., 1991).

NOMENCLATURE:

D_H - hydraulic diameter, m,
f - friction coefficient,
H - total enthalpy, J,
h - specific enthalpy, J/kg,
$\dot{m}$ - mass flow, kg/s,
p - pressure, Pa,
q - volume heat flux, W/m^3,
t - time, s,
u - fluid velocity, m/s,
V - volume, m^3,
x - spatial coordinate, m,
ρ - density, kg/m^3.

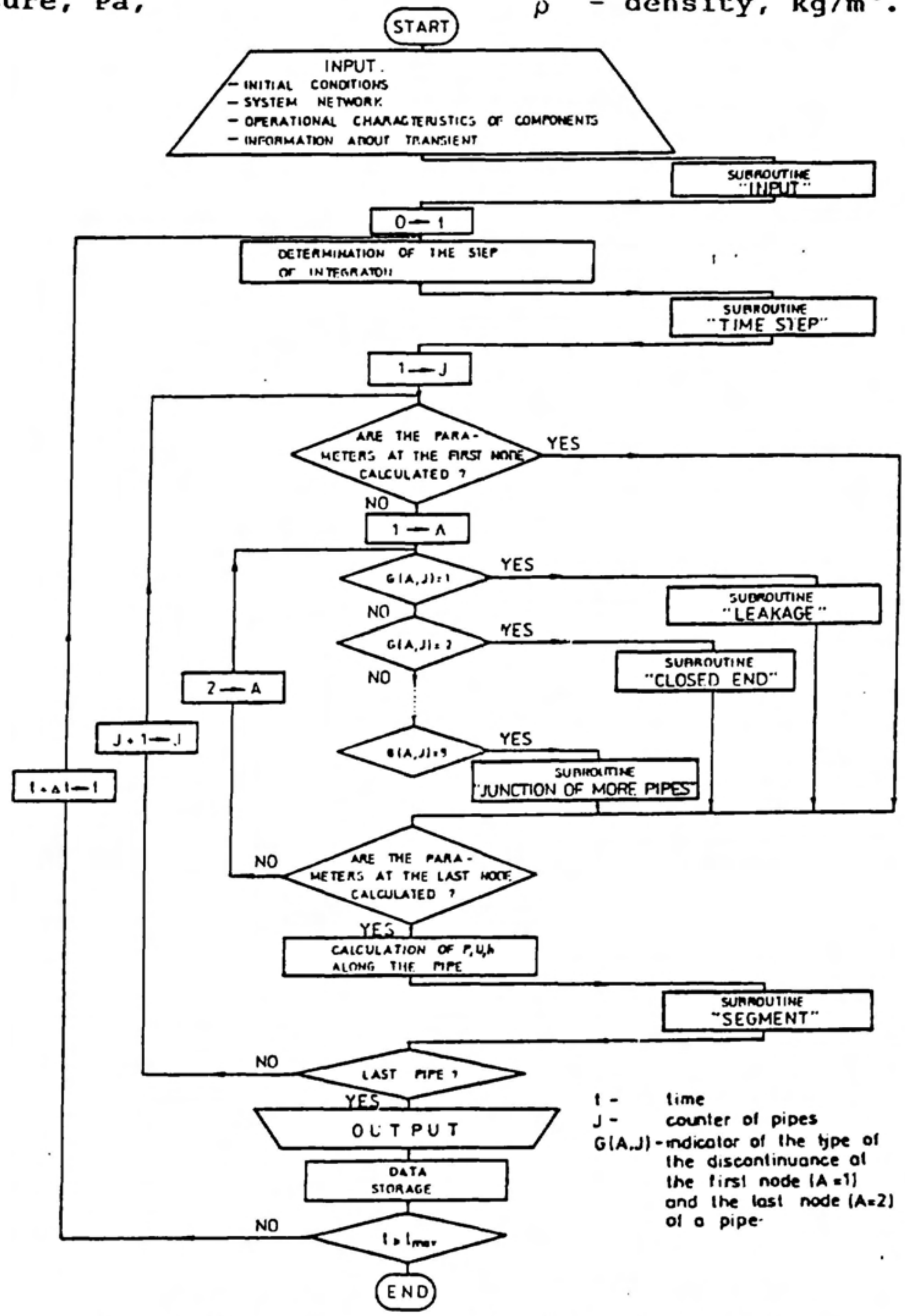

Fig.1 The algorithm of the TEA-01 code

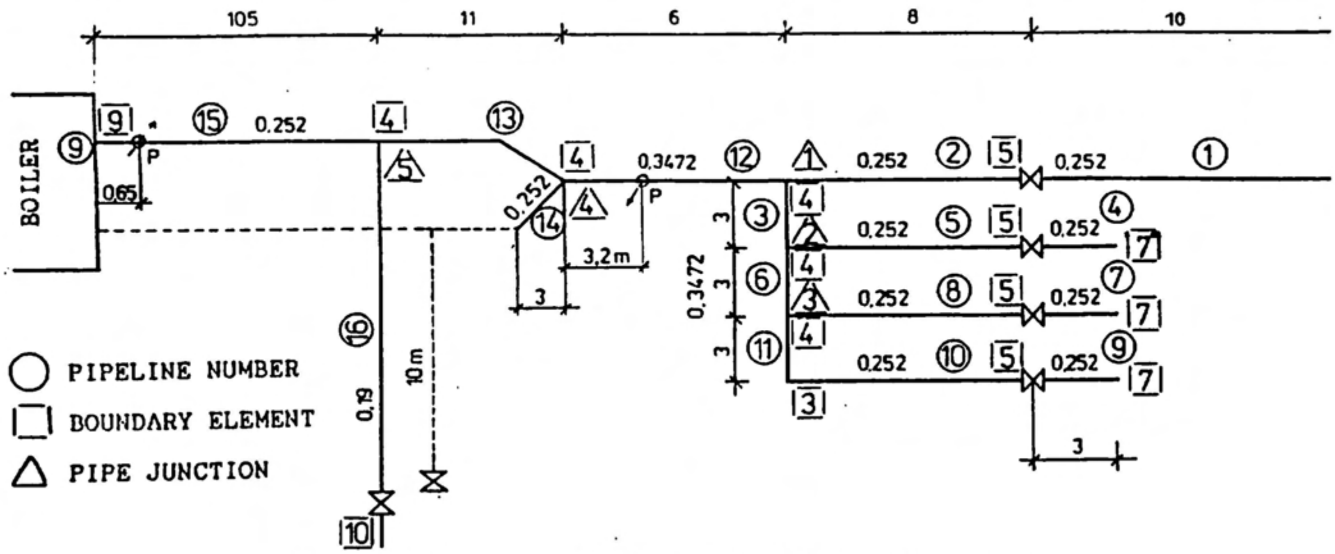

Fig.2 Nodalization of the main steam line

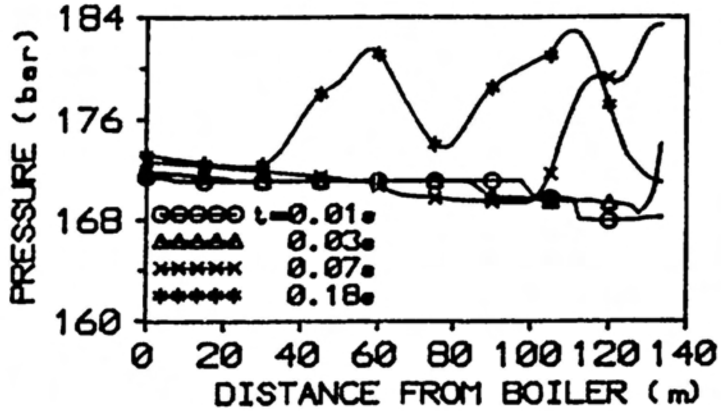

Fig.3 Pressure distribution in the main steam line (isolation valve closure for 30ms, by-pass activated at 0.1s)

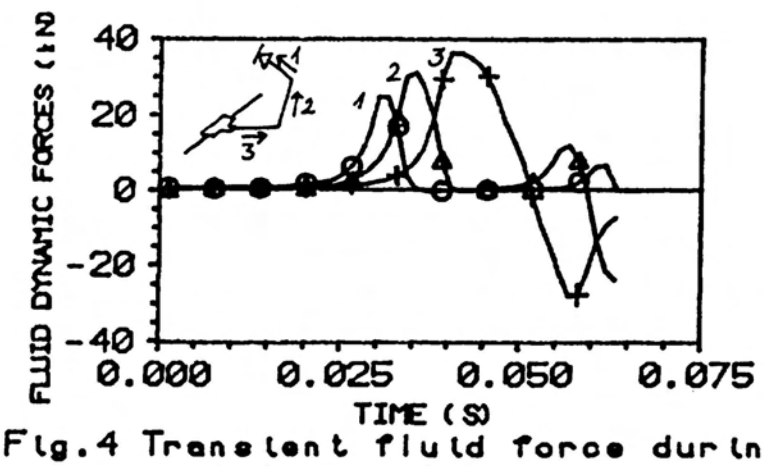

Fig.4 Transient fluid force during the isolation valve closure for 30 ms

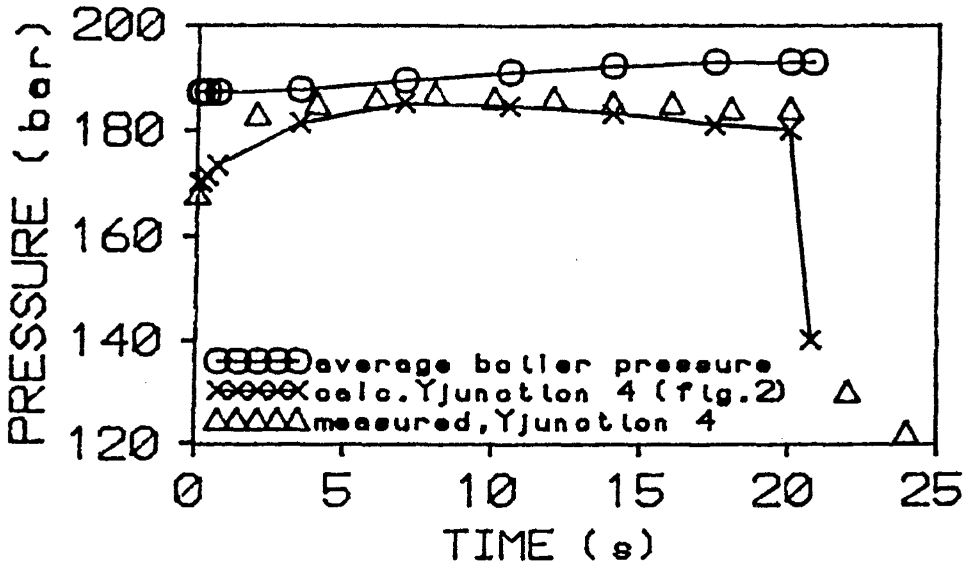

Fig.5 Pressure change before the pipe break (isolation valves are closed, by-pass is activated)

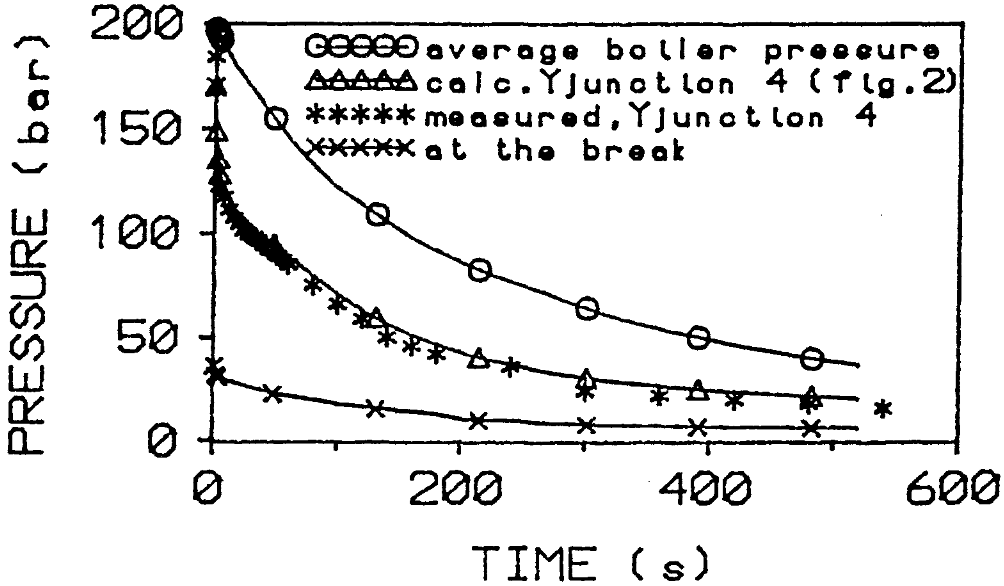

Fig.6 Pressure change during blowdown

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Conclusions and recommendations

Results of Firebird III Mod 1.0 simulation of a liquid relief valve failure indicate that without operator actions the heat transport system and the degasser pressures will rise till the opening of the degasser relief valves leading to a D2O spill.

Therefore operator actions are considered with respect to controlled decrease of power, to determine if they are effective in preventing or delaying RV 11/21 opening.

When the reduction of power (0.5 %/s), starts at the beginning of the transient, the heat transport and the degasser pressures fall below the opening of the degasser relief valves during the time (1200 s) of the run. But the minimum pressurizer level is too low.

For that reason it is recommended the same reduction of power when the pressurizer level stops to drop. At this time the heat transport pressure and the degasser pressure are almost equal.

Under these circumstances the shrinkage experienced by the system is in part compensated by the feed that tries to fill the primary circuit. The operator should have sufficient time to take action on avoid the degasser condenser relief valves opening.

On the other hand, a full manual trip is not considered because the pressurizer empties, and the system pressure may easily reach one of the signals for the automatic actions of the ECC.

References

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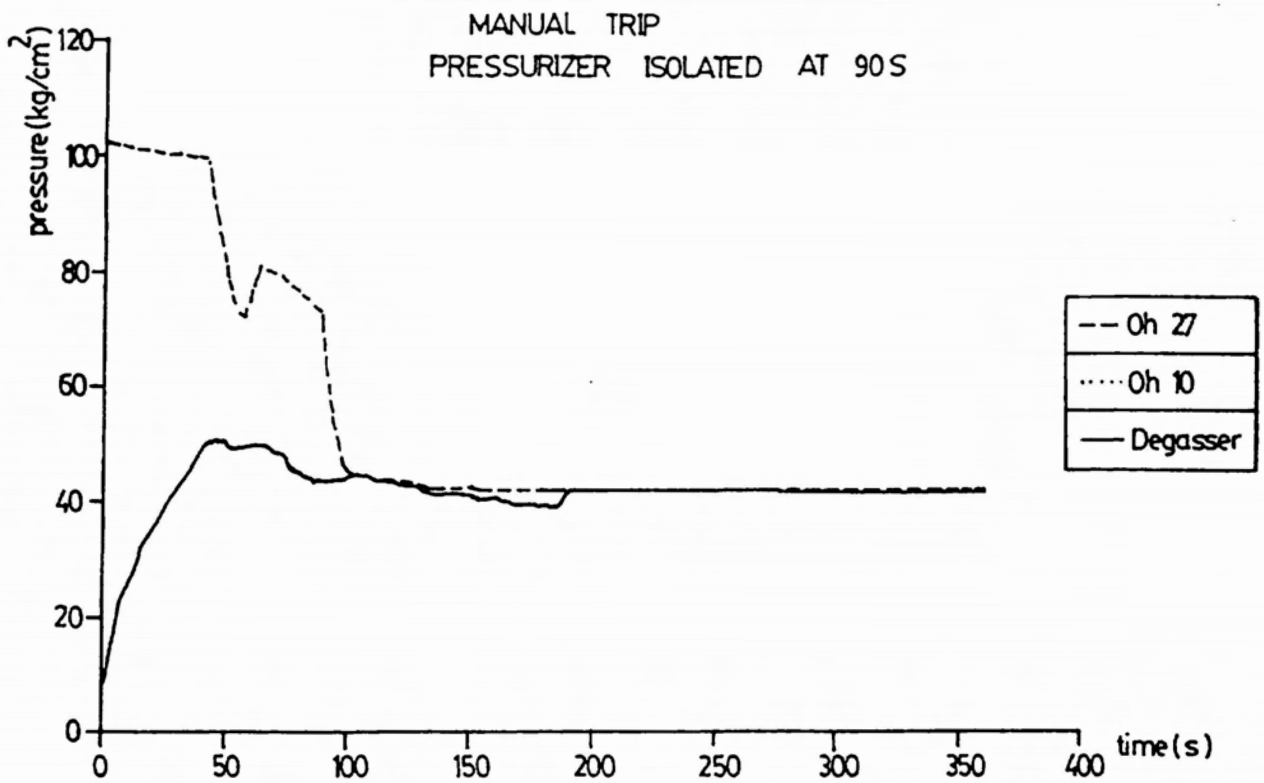
MANUAL TRIP
PRESSURIZER ISOLATED AT 90 S
pressure (kg/cm2)
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
time (s)
Oh 27
Oh 10
Degasser

Figure 10