Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

Study of the Stress Effects of Workers in Nuclear Power Plants On Thermodynamics Laws

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1. Introduction

The current nuclear power generation is not gaining the trust of the government (Nuclear Safety and Security Commission) and the public, despite the design safety of the system itself. The system of nuclear power generation is basically guaranteed to be as safe as the valve being F.C (Fail Close), assuming any worst-case scenario. In the end, however, machines are only machines, and are manipulated by humans, so there is no denying that if a series of complex situations (human errors) occur, accidents such as those of Three mile Island (1979) are likely to occur as well. This study begins with the question of the possibility of human manipulation errors due to the stress caused by work. Here, I will solve the relationship between work and stress in nuclear power plant in terms of 1 and 2 of the laws of thermodynamics. Therefore, I will analyze the stress of workers in a plant (consisting of 2 units) from the perspective of energy.

2. Fluid Dynamic Model

In a flow field, the fluid has a continuous equation, a momentum equation, and an energy equation. The flow of fluid is not important in this study, so it should be an introduction.

$$\frac{\delta p}{\delta t} + \nabla\cdot(\rho \mathbf{V}) = 0 \qquad (1)$$

The Navier - Stokes equation of the incompressible flow of a fluid with a continuous equation and a constant viscosity coefficient is as follows.

$$\rho\frac{D\mathbf{V}}{Dt} = -\nabla p + \mu\nabla\cdot\nabla\mathbf{V} + \rho\mathbf{g} \qquad (2)$$

And the most common energy equation that can be applied to all flows is as follows.

$$\rho\frac{d\hat{u}}{dt} + p(\nabla\cdot\mathbf{V}) = \nabla\cdot(k\nabla T) + \Phi \qquad (3)$$

In this study, we will proceed with the study by assuming that the power plant is on flow of work. Therefore, we will explain instead that energy is also generated by the flow of fluid in the equation (3) above. The amount of work given to an individual or all members is classified by the flow of work, and the flow of work can be classified as follows.

◦ Laminar flow of work: Ordinary State in NPP

◦ Turbulent flow of work: O/H or Plant Trip, Fire in Uljin, etc. (extremely busy situation)

This study seeks to perform a thermodynamic analysis in a turbulent flow of work. (When the power plant is O/H).

The appropriate work Re Number that separates laminar and turbulent flow of work will be left as a future research project.

3. Thermodynamic 1st Law

The energy balance equation in differential form is:

$$dE = \delta Q - \delta W \qquad (4)$$

The meaning of δ in equation (4) is that it is a function of the path, not property. It means that the amount varies depending on the way things are done (autonomous, authoritarian, formal, etc.). Representing the above equation as per unit of time on individual, it is as follows:

$$\dot{Q} - \dot{W} = \Delta E \ (\Delta E = \Delta U + \Delta PE + \Delta KE) \qquad (5)$$

Here, $\dot{Q}$: unit of the amount of work given in addition to the original work at the time of O/H

$\dot{W}$: unit of the amount of work done by in addition $\dot{Q}$ to the original work at the time of O/H

Thus, ΔE can be seen an individual the amount of energy change. (i.e., the amount of stress)

Here, ΔU: The original stress energy that everyone has himself. (personal family history, financial status, etc.)

Δ PE: Stress energy of a plant (organizational culture, site location, etc.)

Δ KE: Stress energy due to environmental changes within the plant (plant trip, environmental change (wildfire), etc.)

If you think of the entire power plant as a control volume, Mass becomes people. If the members of the power plant are in fixed number, it is the best state to work. But the reality of the current power plant is that it is not. Here we will look at the distinction between an individual and entire power plant.

$$\sum_1^n m = M \text{ (Total Power Plant People)} \qquad (6)$$

$$\frac{dEcv}{dt} = \dot{Q} - \dot{W} + \dot{m}_i\left(u_i + \frac{{v_i}^2}{2} + gz_i\right) - \dot{m}_e\left(u_e + \frac{{v_e}^2}{2} + gz_e\right) \qquad (7)$$

If the state of the power plant in the Control Volume is normal, and the above equation is $\frac{dEcv}{dt} = 0$, $\dot{m}_i = \dot{m}_e = \dot{m}$ rearranged, and if the expression is corrected by introducing enthalpy h(h=u+pv) to consider the work caused by the Control Volume,

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}\left(h_i + \frac{v_i^{\,2}}{2} + gz_i\right) - \dot{m}\left(h_e + \frac{v_e^{\,2}}{2} + gz_e\right) \quad (8)$$

Ignoring the kinetic and potential energy effects, the energy conservation equation can be defined as an intensive value with respect to h(T,P). Enthalpy h constructs a table with experimental values for each material, interpolating between intervals to obtain the values.

Here I would like to propose a stress enthalpy(S_h) with the same energy dimension. I have also considered whether S_h can be defined as an intensive value by any S_h(I,S) value.

◦S_h(I,S) : Stress enthalpy
◦I : work importance
◦S : work intensity

Since KHNP is a huge organization, we classified the work by using only power plants as an example. I think that we can quantitatively represent Stress enthalpy according to the task and dividing it into several factors, such as work intensity, work importance, etc.

Table 1. Division of power plant operations according to work intensity and importance (e.g. 2D)

Intensity → Importance↓	3	4	5
3	Approval/ Inspection	2nd System Maintenance	MCR Operator
4	Radiation Manage	Periodic Tests	Rx Activity Management
5	Quality Assurance	1st System Maintenance	Rx Maintenance

* Condition: Extreme busy state(O/H)
** 1,2 is omitted by paper size

Table 1. is example that I set in task arbitrarily by assuming an O/H period in just 2 factors (work intensity, work importance). If we divide the intensity and importance by 1 to 5, it can be listed according to the work overload. Of course, if you add up to worker's the years of an occupational position. it will be possible to expand to 3-D. And if the stress value corrected for reality is obtained, it can be implemented by the following equation.

$$\frac{S_{h1}}{S_{h0}} = (A_1 + A_2 + A_3 + \cdots) \quad (9)$$

If S_{h0} can be defined as the original stress enthalpy in the example above, then S_{h1} adds several coefficients to it to obtain the actual stress enthalpy value. The intention is to add or subtract several factors (business integrity, business evaluation, peer evaluation, etc.) so that they can represent real value. And the equation of (9) is just an example. Also, the example in Table 1. is my own discretionary classification, and if the opinions of the various managers are combined, it could be a denser Chart.

Assuming an entire power plant has finished its O/H (Adiabatic Closed Sys.) (Q eventually disappears)

$$\Delta E = -W \quad (10)$$

The above equation means that during O/H, the stress energy of the entire power plant is created as much as it does the work.

4. Thermodynamic 2nd Law

The Clausius Inequality is introduced that is applicable to any cycle without regard for the body, or bodies, from which the cycle receives energy by heat transfer or to which the cycle rejects energy by transfer. The Clausius inequality states that

$$\oint\left(\frac{\delta Q}{T}\right)_b \leq 0 \ \text{ or } \ \oint\left(\frac{\delta Q}{T}\right)_b = -\sigma_{cycle} \quad (11)$$

The symbol $\oint$ indicates that the integral is to be performed over all parts of the boundary and over the entire cycle. For more information, see Chapter 6 in Ref.[1]

Here, σ_{cycle} can be viewed as representing the "strength" of the inequality. σ_{cycle} has the following meaning:
$\sigma_{cycle} = 0$: no irreversibilities present within the system
$\sigma_{cycle} > 0$: irreversibilities present within the system
$\sigma_{cycle} < 0$: impossible

Here, the property entropy S is introduced in reversible process.

$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T}\right)_{int\ rev} \quad (12)$$

Entropy balance for closed system is generally

$$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma \quad (13)$$

The left side can be considered an entropy change, the right side integral term is the amount of entropy transfer, and the σ the amount of entropy production.

If we think an enlarged system comprising a system and that portion of the surroundings affected by the system as it undergoes a process. Since all energy and mass transfers taking place are included within the boundary of the enlarged system, the enlarged system can be regarded as an isolated system.

An energy balance for the isolated system reduced to

$$\Delta E]_{isol} = 0 \quad (14)$$

This is the sum of its values for the system and surroundings, (14) can be written as

$$\Delta E]_{system} + \Delta E]_{surr} = 0 \quad (15)$$

An entropy balance for the isolated system reduces to

$$\Delta S]_{isol} = \sigma_{isol} \quad (16)$$

Since entropy is an extensive property, (16) can be written as

$$\Delta S]_{system} + \Delta S]_{surr} = \sigma_{isol} \geq 0 \quad (17)$$

This is the increase of entropy principle.

The entropy of the entire power plant is supposed to flow in a direction that increases regardless of the creation, movement, or neglect of work. In this equation of entropy, if we think of T as the force that wants to work, that is, the size of the labor force, we can think of this equation as progressing as the labor force continues to decrease. As entropy increases, the labor force of power plant workers eventually decreases, and stress is created. According to physicist 'Erwin Schrodinger', "All living things live by continuously absorbing negative entropy from their surroundings. Negative entropy is the food of life. Life destroys the order of its surroundings and cannot survive unless it is absorbed by its own body." In other words, for humans, the normal state is to do nothing.

5. Availability(Exergy) Analysis

Typical availability is expressed in the following equation:

$$A=(E-U_0)+P_0(V-V_0)-T_0(S-S_0) \quad (16)$$

The subscript 0 here refers to the equilibrium state within the Dead State, which means that the value of any Availability is greater than or equal to the value of the Dead State (the value of the environment). Any system is naturally destined to go to a dead state. This means that the availability of at least any state of the system is greater than or equal to 0.

Applying availability to the Closed system, the energy equation and the entropy equation are as follows:

$$E_2 - E_1 = \int_1^2 \delta Q - W \quad (17)$$

$$S_2 - S_1 = \int (\frac{\delta Q}{T})_b + \sigma \quad (18)$$

If we sum up the formula by the amount of availability change in these two expressions,

$$A_2-A_1= \int_1^2 \left(1-\frac{T_0}{T_b}\right)\delta Q - [W - p_0(V_2 - V_1)] - T_0\,\sigma \quad (19)$$

is derived by equation (19).

The A2-A1 values can be positive or negative, but the important thing here is,

$I = T_0\sigma$(irreversibility) is.

$$I:\begin{cases} > 0 & \text{irreversibilities present within th system} \\ = 0 & \text{no irreversibilities present within the system} \end{cases} \quad (20)$$

If there is no movement of work and heat in the closed system, and availability does not move,

$$\Delta A]_{isol} = -I_{isol} \quad (21)$$

The value of I_{isol} is unconditionally positive, so the only process in the actual isolation system must be in the direction in which Availability decreases. In conclusion, the increase in entropy and this availability are interrelated concepts. Entropy increases and Availability decreases. Again, all the abilities that a person has are reduced in the direction of decreasing them. Each person has a different Exergy, so the point is to make Exergy dissipate a little slower or enhance the Exergy. With the process of labor, eventually Availability is exhausted and forced to return to disorder, that is, helplessness. In other words, work is simply the use of useful energy. Work is simply the process of getting rid of useful energy, and it is a natural process that is bound to produce stress.

6. Suggestion for the Head of NPP

The sum of the amount of work given per individual is the same as the amount of work done by the entire NPP (operator, mechanic, operational assistant, etc.). It would be best for anyone to work equal, but it's not. Unfortunately, it is also true that the current NPP is divided into preferred/not preferred department. It is also true that the thought of caring for the other person is also insufficient due to the many tasks in the power plant where everything is connected. So, we must quantify the amount of work that is appropriate and distribute the work per individual to a certain extent, Or, if someone has carried too much work on his own, the Head of NPP must take care of hard workers such as giving incentives or considering moving job position.

7. Conclusion

I have been working under an organization where the safety of the people is our top priority, and that is why company has become more and more rigid. Also, I despair at the reality of the recent when I see my colleagues who are tired of repeated and duplicate things because of the bulky organization and the not-systematic work. In this study, I tried that the attempt to represent the psychological or medically qualitative element of a person's stress, in quantitative values. This may be not common sense in engineering, but I hope it will be an opportunity to think about how much stress colleagues in the power plant are exposed to.

If I have a chance, I hope to study the stress quantification approach through O/H process diagram and work order analysis.

REFERENCES

[1] Fundamentals of Engineering Thermodynamics, 3rd Edition, Moran & Shapiro.
[2] Fluid Mechanics, 2nd Edition, Frank. M. White
[3] Entropy, Jeremy Rifkin, p78~82 (Korean Version)