3. Development of Total Temperature Probe

In this chapter, the development of originally designed total temperature probe, to measure the vortical cold flow of VT, and its development history is explained.

3.1 Objective

In this research, I am focusing on measuring total temperature and Pitot pressure of the cold flow. This is because energy separation in the VT is expected to occur mainly in a vortical flow in a vortex chamber. Therefore, the flow structure and temperature distribution in the cold flow, which is close to the vortex chamber, is expected to be closely related to that of the vortical flow in the vortex chamber. Therefore, the information of vortical cold flow from the cold exit is expected to provide insights about the ESM in the VT. In the literatures published in the past, the temperature measurement of the cold flow has been conducted, but the obtained measurement data cannot be clearly judged whether it is total temperature or static temperature. The measurement of a static temperature is difficult because insertion of a probe into a flow unacceptably changes the static temperature at the measurement point. On the other hand, a total temperature at cold/hot exits are much more important than a static temperature in order to evaluate the thermal performance of VT. Therefore, I focus on measuring the total temperature in this research.

When measuring the total temperature of a flow, we need to remember the relation between static temperature and total temperature in a flow;

$$T_s = T_t / \left[1 + \frac{\gamma-1}{2} M^2\right] \tag{2.1}$$

where T_s, T_t, γ, and M is the static temperature, the total temperature, the specific heat ratio and the Mach number, respectively. From Eq.(2.1), it is clearly understood that static temperature decreases as the Mach number increases. In order to measure the total temperature as precisely as possible, the flow must be decelerated enough at the temperature measurement point of the probe.

Figure 3.1 shows an example of conventional total temperature probe[34] used in a high-enthalpy flow. As can be seen in the figure, a thermocouple is inserted in a shield. There are vent holes to discharge the flow and introduce the fresh gas into

the probe. The flow inside the probe should be decelerated as much as possible, to sufficiently recover the kinetic energy of the gas flow as a dynamic temperature. It should be noted that the flow inside the tube must not be in a stagnation state, which will lower the measured temperature by thermocouple than actual total temperature of the gas because the tip of the thermocouple is expected to suffer from inner wall temperature of shield pipe by heat conduction in a hot flow. Therefore, the vent hole is supposed to be as small as possible to sufficiently decelerate the flow in the probe. Figure 3.2 shows the experimentally obtained relation between the vent hole to entrance area ratio and measured total temperature in Ref.[34]. From this figure, it is understood that the vent hole area should be less than 25% (1/4) of the entrance area of the probe. It should be noted that this total temperature probe can only be use if the direction of the flow is known. The flow discharged from the cold exit of the VT is a vortical flow. Therefore, a total temperature probe which can measure a total temperature in a vortical flow is needed.

In this research, 3 types of total temperature probe are created. An evaluation experiment is conducted to determine the measurement error of the probes. A vortical flow is suitable to validate the probes, however, total temperature in a vortical flow is unknown, and therefore, it cannot be used for the evaluation test. Therefore, in this research, a subsonic flow discharged from a sonic nozzle in different angles is used. The details of the procedure and results will be explained in the next 2 sections.

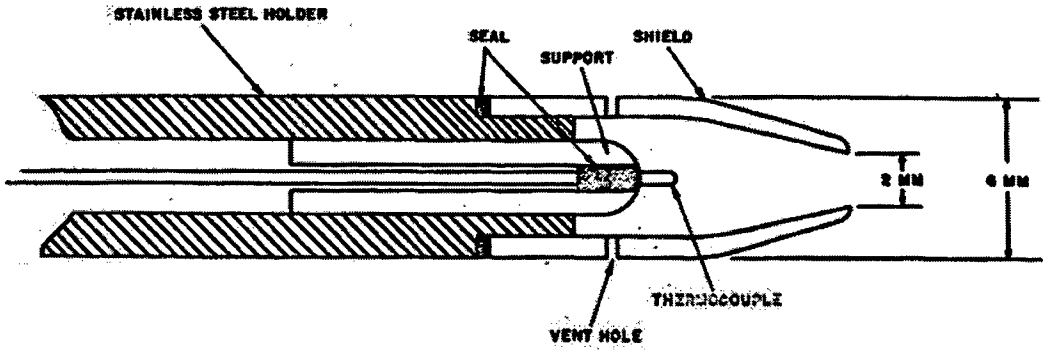

Fig. 3.1 Example of conventional total-temperature probe used in a high-enthalpy flow[34]

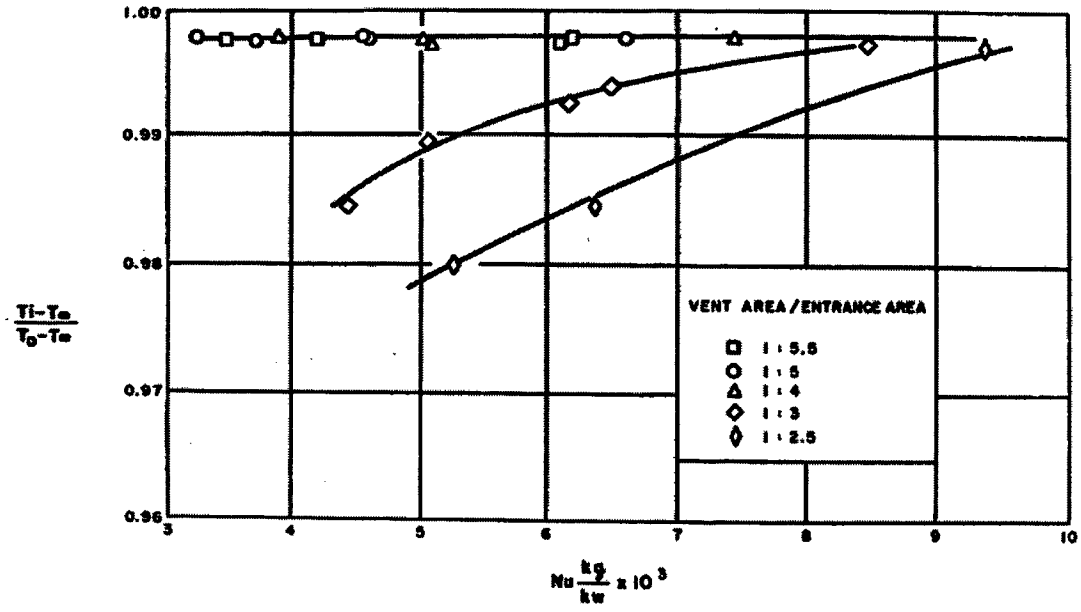

Fig. 3.2 Variation of total temperature probe performance with vent to entrance area ratio[34]