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Analysis of SLF Interruption Performance in self-blast Gas Circuit Breaker

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복합소호형 가스 차단기의 SLF 차단 성능 해석

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ABSTRACT

A self-blast type gas circuit breaker has been studied in this study to improve efficiency of interrupting performance of short line fault(SLF). Hot gas flows of gas circuit breaker have been simulated to evaluate interruption performance using CFD. Design parameters such as various types of expansion chamber and nozzles are suggested by using simulation results. Simulated results and experimental ones are compared with previous (ones that of in under development and with capacitor) GCB. Modified new shape of an expansion chamber and nozzle has been suggested to improve the efficiency of gas flow and to provide guidelines for designing self-blast breaker with a higher interruption capability.

Keywords : GIS(가스절연개폐장치), GCB(가스차단기), Self-blast(복합소호), SLF(근거리선로고장), Circuit Breaker(차단기)

1. Introduction

Recently, Circuit Breaker(CB) is a device that protects important equipment in power network such as power transformers and generators to ensures the safety of power network system by eliminating fault current. CBs should not only eliminate fault current when faulty situation occurs on network by separating contact, but also enables current to flow without electrical and mechanical issues under normal condition.

CBs are usually classified by insulating medium like oil circuit breaker(OCB), vacuum circuit breaker(VCB) and gas circuit breaker(GCB) etc. Recently, VCB and GCB are commonly adapted into the system. VCB is mainly used for power distribution class while GCB is for power transmission class.

A self-blast system which is using arc energy itself to induce a pressure buildup in expansion chamber has advantage of reducing the driving energy. In

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developing self-blast type GCB, the key design factors could only be obtained through numerous trials and errors which takes long time and huge cost. Hot gas simulation is an essential to reduce numbers of experimental trials and also to understand the complex phenomenon of the interrupting mechanism. Interrupting characteristics are directly related to the gas density and temperature distribution at arc region. Based on the density and temperature distribution obtained by the simulation, heat and genetic fracture characteristics are grasped to determine the capability of the interruption.

The operation of the CB in the system can be roughly divided into following two functions. One is to disconnect cables, capacitor banks and long-distance transmission lines. At this operation, it is required for CB to interrupt a relatively low current. The other one is to cut off the fault current when an accident such as a short circuit (SLF, Short Line Fault) or ground fault (BTF, Bus Terminal Fault) occurs in the system. Thus, it is essential for CB to have a small current and a large current interruption performance at the same time.

GCB with a capacitor between the contacts, has an advantage of gradual TRV(transient recovery voltage) increase at contact separation. However, the capacitor may induce resonance issue in connection with transformer and PT in the system. Thus, a capacitor-less(C-less) GCB is required for the case. But then, GCB without capacitor shows a steep TRV increasing slope and it causes thermal breakdown between the contacts which means deteriorating in SLF interruption performance.

In this paper, to ensure SLF performance of 362kV 63kA GCB, hot gas flow phenomenon is simulated by four design parameters of length/diameter(L/D) ratio and volume of the expansion chamber, nozzle throat length and shape. Result indicating a high pressure in the chamber and showing lower temperature distribution at the arc region is considered having better interruption performance. The

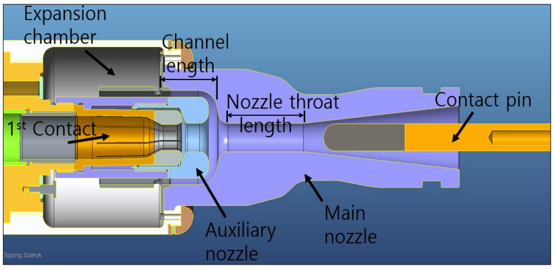


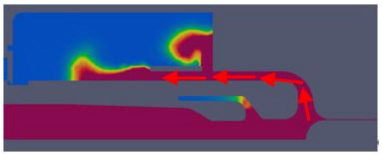
Fig. 1 Inner structure of GCB

simulated results are compared through the most critical moment which is medium arcing time of 13.8ms among the three arcing times(Min., Med., Max.). Results at Max. (17.5ms) arcing time is additionally compared for those of cases having difficulty in evaluating. [1 - 6]

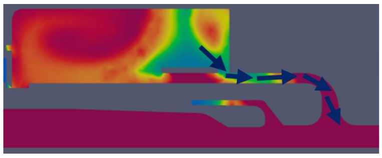
2. Simulation

General shape of self-blast type GCB is shown in Fig. 1. When contacts are separating, arc is generated between the contacts at large current phase. Heat and energy generated by the arc increases the pressure in the expansion chamber and the pressure pushes cold gas back to the arc region at Current-Zero(CZ) to interrupt the arc. This is the basic interruption principle of self-blast type GCB. As the principle, interruption capability is closely related to the pressure rise in the chamber. Since the nozzle and expansion chamber are the major requisite of the pressure, proper nozzle and chamber design should be considered.

To secure SLF interruption performance, next two conditions must be satisfied. Sufficient pressure rise in expansion chamber to acquire strong arc cooling power, and flows of a high density (i.e. low temperature) gas from the chamber to the arc region to ensure dielectric recovery after CZ. To satisfy required conditions of pressure and density for the interruption, hot/cold gas needs to flow smoothly along nozzle wall. For expansion chamber, it is necessary

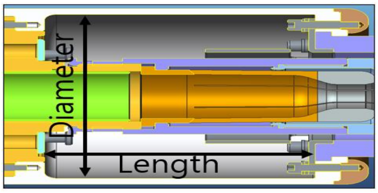


(a) Hot gas flowing from arc region to expansion chamber at large current phase

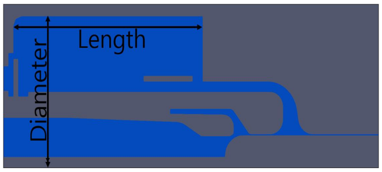


(b) Cold gas flowing back to arc region at CZ

Fig. 2 Distributions of gas flows at large current phase and CZ



(a) L/D in 3D modeling



(b) L/D in simulation

Fig. 3 Definition of L/D

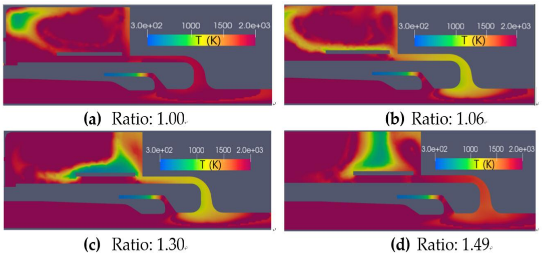


Fig. 4 Temperature distribution at CZ of each model with different L/D ratio chamber [p,u]

to have suitable shape and volume to increase the pressure and lower the temperature. Distributions of gas flows at large current phase and CZ is shown in Fig.2.

2.1 Length/Diameter ratio (L/D) of expansion chamber

To see the interrupting performance dependence on design parameter in expansion chamber, models with different L/D are been simulated. Definition L/D meaning in this paper is shown in Fig. 3.

Temperature distribution at CZ with different L/D is shown in Fig. 4. The chamber volume of each models are same, and only the difference between the models is L/D ratio. The result of temperature distribution in the arc region shows similar between (b) and (c), that are indicating the lowest temperature at middle arching time.

To evaluate interruption performance of (b) and (c), simulation results of maximum arcing time are compared as shown in Fig. 5. Lower temperature at arc region can be seen in model (c). Comparing the amount of the cold gas remaining in the chamber of each model, less cold gas can be seen in model (b). It is considered that, due to the vigorous hot gas flow inside of the expansion chamber, gases been blended and heated up prior to CZ.

To evaluate interruption performance of (b) and (c), simulation results of maximum arcing time are compared as shown in Fig. 5. Lower temperature at arc region can be seen in model (c). Comparing the amount of the cold gas remaining in the chamber of each model, less cold gas can be seen in model (b). It is considered that, due to the vigorous hot gas flow inside of the expansion chamber, gases been blended and heated up prior to CZ.

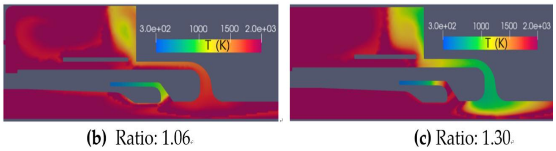


Fig. 5 Temperature distribution at maximum arcing time

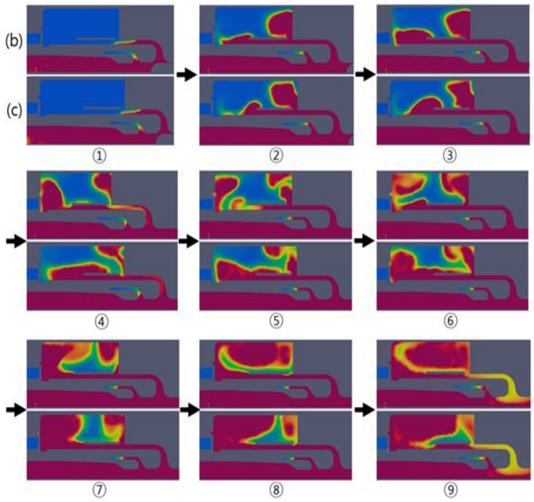


Fig. 6 Distribution of hot gas flux inside the chamber of model (b) and (c) over the same period of time

Trace of the hot gas flux inside the expansion chamber of model (b) and (c) over the same period of time are shown in Fig. 6. As shown in the Fig. 6, at time period of ③, hot gas in model (b) reaches the end of the chamber wall earlier than that of (c). The reached gas bumped against the chamber wall that of model (b) is reflected and creates a vortex in the chamber and gas inside the chamber is heated up as the vortex grows. The first vortex formation can be seen in model (b) at time period of ④. At the last moment of time sequence in Fig. 7 (b), no cold gas remaining in the chamber can be seen. Which leads to high possibility of interruption failure. It is considered due to the length of model (b) chamber is shorter than that of (c). It is demanded that suitable length and diameter of expansion chamber, required considering the speed of the hot gas, and characteristics of the breaker for the purpose of cooling the arc at a required moment.

The maximum pressure values in the expansion chamber at CZ of each model is shown in Table 1. There is no large variation in pressure values due to the same volume of expansion chamber of all models.

Table 1 Maximum pressure at CZ due to L/D difference of the chamber

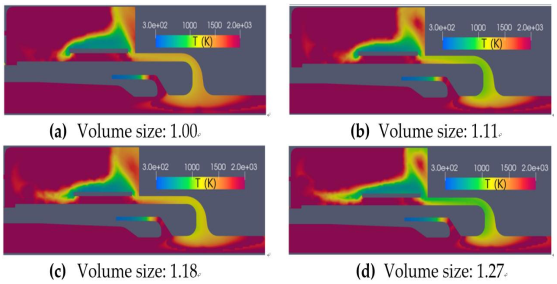
	Pressure (p,u)
(a)	1.25
(b)	1.24
(c)	1.27
(d)	1.24

Table 2 Maximum pressure at CZ due to the chamber volume difference

	Pressure [p,u]
(a)	1.34
(b)	1.30
(c)	1.27
(d)	1.26

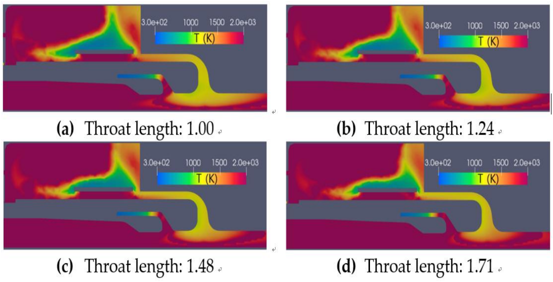
2.2 Expansion chamber volume

Temperature distribution at CZ with different expansion chamber volumes is shown in Fig. 7, and the maximum pressure in the expansion chamber at CZ that of each model with the different volumes are shown in Table 2. As shown in Fig. 7, the better interruption performance is expected in model (b) and (d) due to the lower temperature distribution, and by contrast of the Table 2, model (a) shows maximum pressure value, which has intimate relation with the interruption success(higher the better). As each result leads different best candidate, it is hard to identify which model has better performance just by comparing simulation results. However, in order to secure BTF interruption performance which has higher fault current than SLF, a certain margin of cold gas volume in expansion chamber is required. Which means when maximum pressure value and temperature shows similar, it is considered that chamber with larger volume might have better interruption capabilities. Chamber should have enough volume to secure BTF interruption but also small enough to increase the pressure. To resolve this contradiction, adopting additional method is recommended to increase the pressure (not only by decreasing the volume) such as material of nozzle and etc.



(a) Volume size: 1.00 (b) Volume size: 1.11 (c) Volume size: 1.18 (d) Volume size: 1.27

Fig. 7 Temperature distribution at CZ with chamber volume difference [p,u]



(a) Throat length: 1.00 (b) Throat length: 1.24 (c) Throat length: 1.48 (d) Throat length: 1.71

Fig. 8 Temperature distribution at CZ by the length of nozzle throat length [p,u]

2.3. Nozzle throat length

In general self-blast type GCB, nozzle is necessary not only to control the flows of gas, but also to ensure a pressure rise by inducing an ablation. Nozzle can be ablated by the strong radiant energy of the arc which is created during the contact separation. The ablated nozzle in a form of a vapor, flows toward upstream field(to the expansion chamber) and this makes the pressure rise in the chamber. The longer nozzle throat the more ablation occurs which is directly linked to the pressure rise.

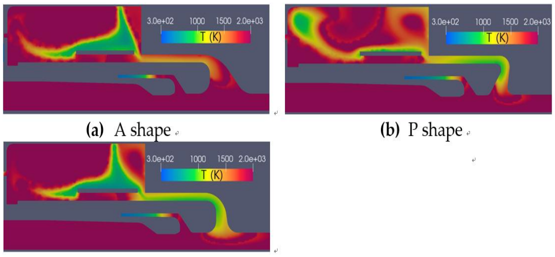
Temperature distribution at CZ of each model with different nozzle throat length is shown in Fig. 8. Table 3 is the corresponding maximum pressure values in the chamber. Similar pattern at temperature distribution for all models can be seen. The pressure of model (d) is the highest which has the longest nozzle throat length. It can be confirmed that nozzle throat length has strong influence to the pressure rise in chamber, but less effect to distributions of temperature. The relation between nozzle throat length and pressure rise is thought to be due to the amount of vapor created by the ablation and the nozzle clogging effect. Until the contact is released from the throat, gas in the chamber will be stagnant for no exit and thereby maximize the pressure rise in the chamber. Although the higher pressure leading to the better interruption performance, a compromise must be found due to the prolong of arcing time as the nozzle throat length increase. The prolonged arcing time could lead interruption occurring at the end of the stroke which has high possibility of failure. It is desired that in initial design procedure, target arcing time should be defined. And in accordance with the arcing time, length of stroke, operation speed, nozzle throat length, etc., sould be decided.

Table 3 Maximum pressure at CZ due to the nozzle throat length difference

	Pressure [p,u]
(a)	1.00
(b)	1.11
(c)	1.22
(d)	1.33

2.4. Main and auxiliary nozzle shape

To confirm the effect of the nozzle shape to the gas flow, 3 different shapes of nozzle have been simulated. Temperature distribution at CZ by different nozzle shape is shown in Fig. 9. D shape nozzle is expected to perform best interruption among the models on the grounds of most widely spread cold gas as shown in Fig. 9. Unlike other shapes no cold gas in A shape nozzle reached the arc region. This is thought to be due to the difference in the cross-sectional area corresponding to the channel part in Fig. 2. Cross-section of each nozzle channel is measured and compared as shown in Table 4. Measured position of channel part is shown in Fig. 10.



(a) A shape

(b) P shape

(c) D shape

Fig. 9 Temperature distribution at CZ by nozzle shape

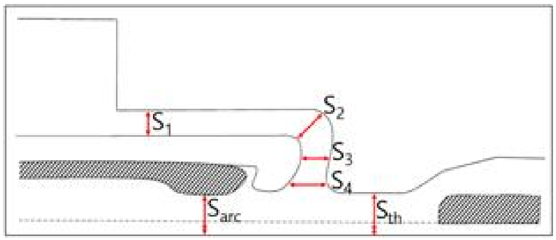


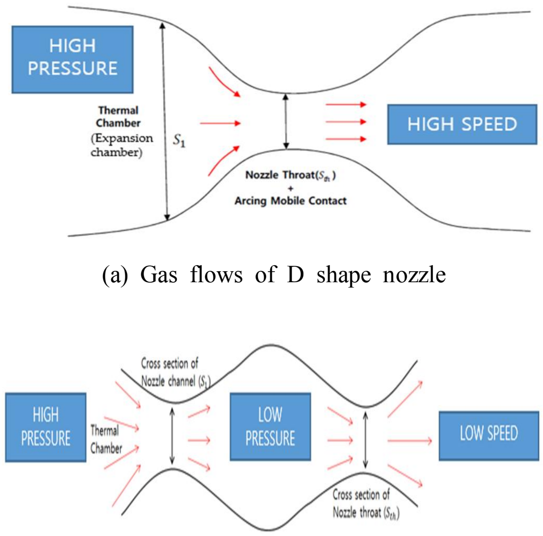
Fig. 10 Measurement positions of the cross-sectional area of gas flow channel

Table 4 Cross-section of each position

Measurement position	Cross-section [p,u]		
	A shape	D shape	P shape
S1(inlet of cold gas)	1	1	1
S2(intermediate)	1.70	1.04	1.23
S3(intermediate)	2.32	0.99	0.89
S4(intermediate)	2.26	0.99	1.03
Sarc+Sth	0.65	0.65	0.65

D shape nozzle has the smallest deviation in cross-section between each measured position, and dimensions decrease linearly from S1 to S4. Cold gas from the expansion chamber will not be utilized efficiently if the cross section of Sarc + Sth which is final outlet of the gas is wider than that of S1 which is inlet of the gas. If the cross-sectional area has a large deviation at S2 to S4, pressure loss is expected and leading decrease of interruption performance. Fig.11 illustrates assumed gas flows of D shape and A shape nozzle. It can be estimated that less deviation in cross section is linked to the better performance.

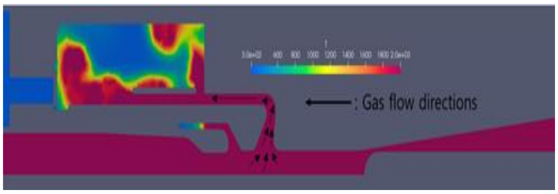
The maximum pressure in the expansion chamber at CZ according to the nozzle shape difference is shown in Table 5. Despite the same volume of expansion chamber, large gap between the results can be confirmed. Reason for the gap is considered to be that of changes in directions of gas flow at a step where ablated nozzle steam flows along the nozzle wall at the large current phase. Direction of the flow changes vertically where at S2 position of P shape as shown in Fig. 12, which the model shows lowest pressure among the results. In order to increase the interruption performance, it is required that the nozzle having a shape that does not disturb the gas flow and capable of transmitting pressure efficiently.



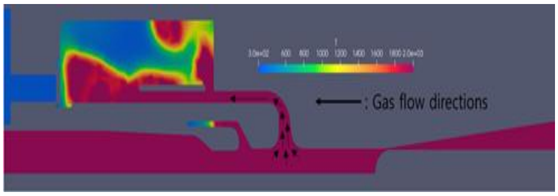
(a) Gas flows of D shape nozzle

(b) Gas flow of A shape nozzle.

Fig. 11 Assumed gas flows of D shape and A shape nozzle



(a) Gas flows of P shape nozzle



(b) Gas flows of D shape nozzle

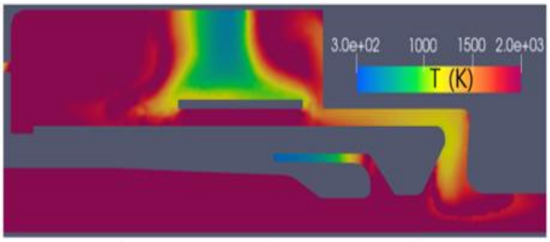
Fig. 12 Gas flow directions of D shape and A shape nozzle

Table 5 Maximum pressure at CZ due to the nozzle shape

	Pressure [p,u]
A shape	1.31
P shape	1.05
D shape	1.29

3. Simulation and Experiment Trial Result Comparison

In process of securing the interruption capabilities through modifying and combining the parameters based on simulation results, diversity of combinations are proposed. All three arc windows are tested in experimental trials. The Results are summarized in Table 6. Previous model did not succeed in interrupting except min window, but some of the improved models, which are combinations of simulation results, have successfully interrupted at all arc windows. The design parameters of the previous model and the interruption succeed model are shown in Table 7.



	Pressure [p,u]
Previous model	1.05

Fig. 13 Temperature distribution of previous model and its maximum pressure

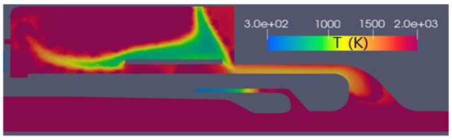
Table 6 Experiment trial results of previous and combined models

	Arc window		
	Min	Med	Max
Previous model	OK with 500pF	NG	NG
Experiment model ①	OK	OK	NG
Experiment model ②	OK	NG	OK
Experiment model ③	OK	NG	OK
Experiment model ④	OK	NG	NG
Experiment model ⑤	OK	OK	NG
Experiment model ⑥	OK	NG	OK
Experiment model ⑦	OK	NG	OK
Experiment model ⑧	OK	OK	OK
Experiment model ⑨	OK	OK	OK
Experiment model ⑩	OK	OK	OK

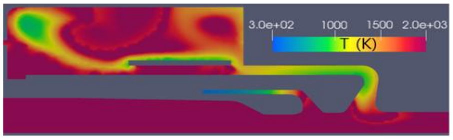
Temperature distribution of previous model and its maximum pressure is shown in Fig. 13. Temperature distribution of model ⑧, ⑨ and ⑩ is shown in Fig. 14. Which succeeded in interrupting in every arc windows. A picture of experimental specimen and test information are shown in Fig. 15.

Table 7 Design parameters of the models

	L/D [p,u]	Volume [p,u]	Nozzle throat length [p,u]	Nozzle shape
Previous model	1.47	1.18	1	P
Experiment model ⑧	1.32	1.20	1.81	D
Experiment model ⑨	1.29	1.17	1.67	D
Experiment model ⑩	1.19	1.21	1.67	D



(a) Experiment model ⑧



(b) Experiment model ⑨

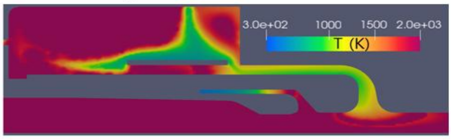
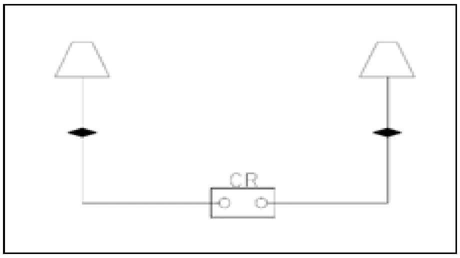


Fig. 14 Temperature distribution of Experiment models



(a) Single line diagram

Operating system : Spring operating mechanism
Rated voltage : 362 kV, rms
Rated frequency : 60 Hz
Rated current : 6300 A
Test duty : SLF 90

(b) Experiment information

(c) Experiment specimen

Fig. 15 Experimental specimen information

4 Conclusion

In this paper, hot gas simulation is performed to improve the SLF interrupting performance of self-blast type GCB. Four design parameters affecting the pressure and temperature distribution, which are the main factor of the interrupting performance are selected and simulated for the efficiency of the performance according to the shape. The conclusions are as follows.

1. Suitable shape of the expansion chamber is required depending on the characteristics of the breaker such as operating speed of the breaker, ablativity of nozzle material, and the magnitude of the interrupting current. Chamber should have enough volume to secure BTF interruption but also small enough to increase the pressure. It is recommended that in purpose of pressure increase adopt other method (not by decreasing the volume) such as material of nozzle and etc.
2. Nozzle throat length has strong influence to the pressure build up in chamber, but less effect to

conditions of temperature. Although longer nozzle throat length leading to the higher pressure which is closely related to the interruption performance, a compromise must be found due to prolong of arching time as the nozzle throat length increase. It is desired that in initial design procedure, targeting arcing time should be defined. And in accordance with the arcing time, length of stroke, operation speed, nozzle throat length, etc., could be decided.

3. Shape of nozzle that is possible to transmit hot gas without disturbing the flow and minimize the pressure leakage is required. To maximize nozzle tube effect, it is better to have linearly decreasing cross-section values of nozzle from inlet of cold gas to outlet of the gas.

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