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Optimization of the HIRFL-CSR Cluster Target*

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Abstract A new gas delivery system is designed and installed for HIRFL-CSR cluster target. The original blocked nozzle is replaced by a new one with the throat diameter of 0.12mm. New test of hydrogen and argon gases are performed. The stable jets can be obtained for these two operation gases. The attenuation of the jet caused by the collision with residual gas is studied. The maximum achievable H_2 target density is 1.75×10^{13} atoms/cm^3 with a target thickness of 6.3×10^{12} atoms/cm^2 for HIRFL-CSR cluster target. The running stability of the cluster source is tested both for hydrogen and argon. The operation parameters for obtaining hydrogen jet are optimized. The results of long time running for H_2 and Ar cluster jets look promising. The jet intensity has no essential change during the test for H_2 and Ar.

Key words heavy ion storage ring, internal target, cluster jet, atomic beam

1 Introduction

HIRFL-CSR, a cooler-storage ring (CSR) project[1], is the upgrading system of the Heavy Ion Research Facility in Lanzhou (HIRFL). It consists of a main ring CSRm and an experimental ring CSRe. The cluster target is located at one straight section of CSRe which can provide the gas target of inert gases and small molecular gases with the expected density of $\geqslant 10^{12}$atoms/cm^2 for the experiments with highly charged ions[2]. HIRFL-CSR cluster target has been finished and installed in the due position of the ring. The test experiments have been done for N_2 and Ar gases. The target thicknesses of 1.2×10^{13}atoms/cm^2 and 1×10^{13}atoms/cm^2 are obtained for N_2 and Ar gases, respectively. The first test with hydrogen is not successful since the pumping speed of Leybold turbo-pumps (T1600) for hydrogen drops dramatically down at the inlet pressure range of 10^{-1}—10^{-2}mbar and it is not possible to obtain a stable hydrogen jet in that case. Stable hydrogen jet is finally obtained after replacing the two Leybold T1600 turbo-pumps with two Varian Turbo-V2000HT turbo-pumps at the nozzle stage, and improving the conductance of the connecting line between the roots pump and the turbo-molecular pumps of the cluster source. The maximum target density of 6.6×10^{12}atoms/cm^2 is obtained for hydrogen[3], but it is not stable due to the problem of nozzle blocking.

In the further test experiments the running of the cluster target system is troubled with the frequent blocking of the nozzle with a diameter of 0.1mm. The system may run for a long time only when liquid nitrogen is used as the inlet gas. The stable jets cannot be obtained for other operation gases. The nozzle blocking is mainly caused by the impurity coming from the inlet gas. The gas purity in the gas source and the cleanness of the gas pipe connecting the gas

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bottle and the nozzle stage should be improved. Thus a new gas feeding system including the high purity gas sources (99.9999%), the gas pipeline of electronic grade, the metal valves, the standard fittings, and the effective gas filter is designed and installed. The original blocked nozzle is removed from the source and a new one having a throat diameter of 0.12mm is installed. The nozzle and skimmers have then been carefully aligned.

New testing of hydrogen and argon gases have been performed at the HIRFL-CSR cluster source with the new gas feeding system. The stable jets can be obtained for these two operation gases. The jet formation under different nozzle pressures is studied, and the running stability of the cluster source is tested both for hydrogen and argon. The operation parameters for obtaining a good hydrogen jet are optimized. The results of long time running for H_2 and Ar cluster jets look promising. The jet intensity has no essential change during the test for H_2 and Ar.

2 Results and discussion

The cluster jet source consists of three vacuum chambers (Fig. 1). The first chamber is the source part of the cluster target; the second one is the interacting chamber where the jet interacts with the ion beams and the third one is the jet dump chamber. The source part includes four stages: nozzle-1st skimmer stage (1st stage), 1st skimmer-2nd skimmer stage (2nd stage), 2nd skimmer-3rd skimmer stage (3rd stage) and 3rd skimmer-4th skimmer stage (4th stage). The clusters are produced during the expansion of the gas in the supersonic part of the nozzle. The cluster beam is formed while passing through the set of the skimmers, giving an intense beam with a well-bounded intensity profile. To get good clusterization, it is necessary to keep the temperature of the nozzle in the range corresponding to the saturation vapor pressure at a given working pressure. The nozzle is thus placed on the second stage of the cryohead and allows the temperature changing from 20K to 300K by using a heater wrapping on the nozzle. The gas flowing into the nozzle is first cooled in the heat exchanger and then cooled down to the temperature of the nozzle.

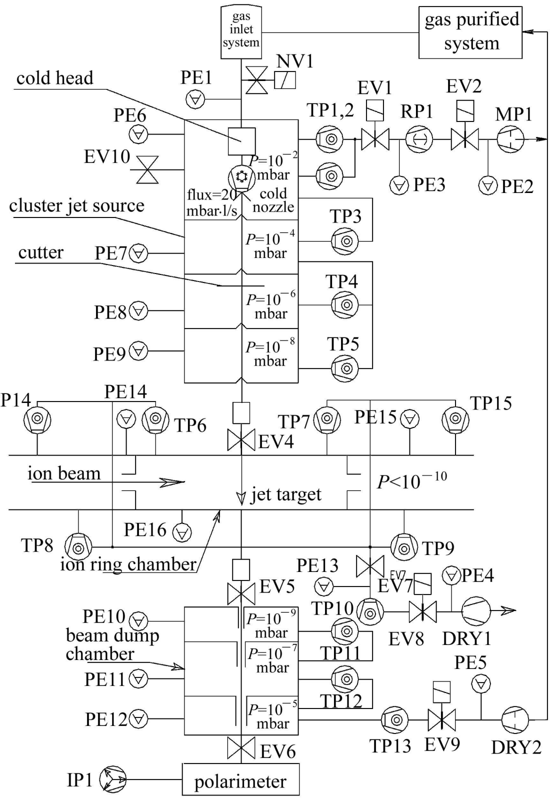

Fig. 1. Layout of the cluster target.
PE: gauge, EV: electropneumatically valve, NV: needle valve, MP: mechanical pump, IP: ion pump, DRY: dry pump, RP: roots pump, TP: turbo pump.

2.1 The pressure distribution in the cluster source

Testing of the H_2 and Ar gas jets was performed at the HIRFL-CSR cluster source. A liquid nitrogen trap filled with charcoal was used during H_2 test to clean the gas coming into the source. Fig. 2 shows the results of pressure measurements in the different chambers of the cluster source versus the nozzle pressure ($P_{\rm no}$) for hydrogen. $P1$, $P2$, $P3$ and $P4$ are the pressures in the 1st, 2nd, 3rd and 4th vacuum chamber for H_2 gas, respectively.

The measurements were done for the possibly lowest nozzle temperature ($T_{\rm no}$) when the nozzle heating supply was switched off. The increase of nozzle temperature in Fig. 2 may be explained by the gas flow heating. Fig. 3 presents the results of pressure measurements in the different chambers of the source versus the nozzle pressure ($P_{\rm no}$) for argon. $P1$, $P2$, $P3$

and $P4$ are the pressures in the 1st, 2nd, 3rd and 4th vacuum chamber for Ar gas respectively.

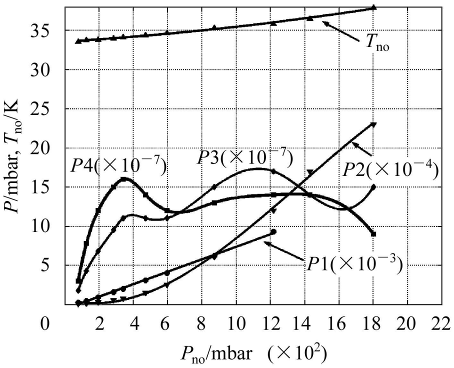

Fig. 2. Pressure reading in different chambers of the cluster source and temperature in nozzle versus the pressure of the nozzle stage for hydrogen.

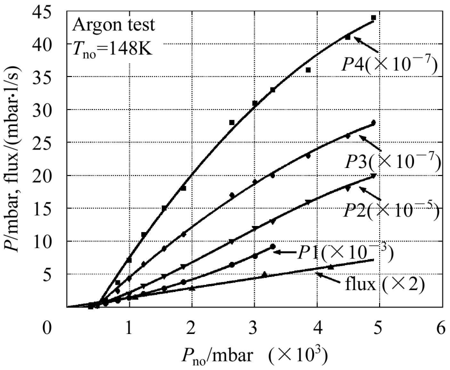

Fig. 3. Pressure reading in different chambers of the source and flux in nozzle versus the pressure of Ar at the nozzle stage.

As it clearly demonstrates that the $P4$ curves for Ar (Fig. 3) and for H_2 (Fig. 2) differ greatly from each other. The intensity of the Ar jet increases in the whole range of P_{no} but the intensity of the H_2 jet increases only in a limited range of P_{no} (up to 350 mbar) and after that the jet intensity goes down, and the maximum flux of the H_2 jet may be achieved at P_{no}=350 mbar. The hydrogen jet may be attenuated by the collision with the residual gas, but the attenuation effect is small in case of the argon jet since heavy clusters will hardly be attenuated through the collisions with the residual gas. The pressures in the 1st and 2nd chambers increase as the P_{no} increases, and the attenuation by the collision with the residual gas will lead to the decrease of the pressures in the 3rd and 4th chambers until the increase of the jet flux and the decrease due to the attenuation achieve the equilibrium. The co-influence of the increase of the jet flux and the decrease due to the attenuation leads to the fluctuation structure of the $P3$ and $P4$ in case of hydrogen jet as shown in Fig. 2, and $P3$ and $P4$ increase monotonously as the increase of the P_{no} in case of argon jet as shown in Fig. 3.

2.2 The maximum H_2 jet density

The main parameter of the cluster source is the maximum possible jet intensity that could be obtained for a stable vacuum condition of the source[4, 5]. One can determine the target intensity by measuring the pressure change in the 4th chamber when the gate valve connecting 4th chamber and interaction chamber is changed from close to open[6].

Considering the pumping speed in the 4th chamber is about 2300·l/s for H_2[6], the H_2 jet flux at the nozzle pressure of 350mbar could be estimated by the products of the pressure change and pumping speed of the 4th stage for H_2:

$$\begin{aligned} Q &= 1.3\times10^{-6}\text{mbar}\times2300\cdot\text{l/s}=3\times10^{-3}\text{mbar}\cdot\text{l/s}= \\ &7.35\times10^{16}\text{mol/s}. \end{aligned} \tag{1}$$

Here 1.3×10^{-6}mbar is the pressure change at the 4th stage when the valve connecting the 4th chamber and the interaction chamber changes from close to open. The density of H_2 jet in the centre of the interaction chamber (interacting point) could be calculated as follows:

$$n=\rho/v/S\ , \tag{2}$$

where ρ(atoms/s) is the intensity of atoms in the jet, v(cm/s) is the velocity of the clusters, S(cm^2) is the cross section of the jet. In the present case the velocity of the H_2 clusters v=8.4×10^{4}cm/s at the nozzle temperature of 34K. The jet diameter at the interaction point estimated from the size of the 4th skimmer is D_{jet}=3.6mm and its area is S=10.0mm^2=0.1cm^2. The jet density is:

$$\begin{aligned} n &= 2\times7.35\times10^{16}/8.4\times10^{4}/0.1= \\ &1.75\times10^{13}(\text{atoms/cm}^3), \end{aligned} \tag{3}$$

which corresponds to a target thickness of d = $1.75\times10^{13}\times0.36 = 6.3\times10^{12}$(atoms/cm^2). The gat jet target at ESR, in Darmstadt, Germany has typical target density of 1×10^{13}atoms/cm^3 for H_2 after cooling the nozzle down to 77K with liquid nitrogen[7]. The H_2 jet density we have obtained is higher than that of the ESR internal target, and is also better than the expected value of 1×10^{13}atoms/cm^3 for H_2.

2.3 The temperature dependence of the H_2 jet intensity

The temperature dependence of the H_2 jet intensity for a given total flux through the nozzle was investigated. The measurements were done for the flow rate of 14.1mbar·l/s. The temperature of the nozzle was controlled by a copper sensor and changed by a heater located on the nozzle. Fig. 4 shows the measured results. In Fig. 4 one can see the H_2 cluster jet intensity decreases dramatically with the increasing of the nozzle temperature.

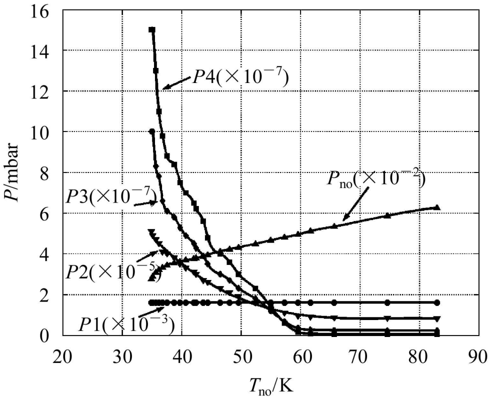

Fig. 4. Pressure reading in different chambers of the cluster source versus the temperature of the nozzle.

2.4 Running stability of the cluster source

To understand the long time running stability of the cluster source, the measurements of pressures reading in different chambers as a function of running time were performed. The test was done both for Ar and H_2 gases. The results are shown in Fig. 5 and Fig. 6. Fig. 5 shows the pressure reading in different chambers of the source and the total flux through the nozzle versus the running time for Ar gas, and the nozzle temperature was 139K. Fig. 6 shows the pressure in different chambers of the source versus the running time for H_2 gas, and the nozzle temperature was 34K. The total flux through the nozzle was 13mbar·l/s. As one can see in Fig. 5 and Fig. 6, the results of long time running for Ar and H_2 cluster jets look promising. The jet intensity is no essential change during the test time.

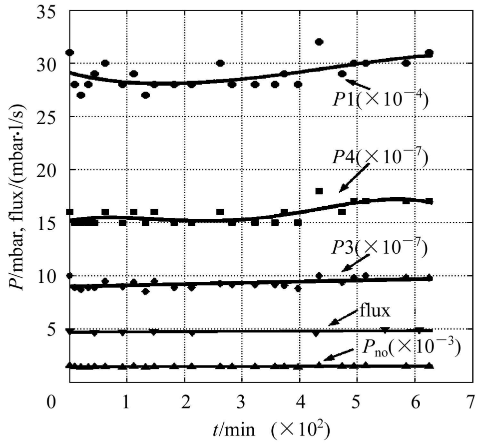

Fig. 5. Pressure in different chambers of the cluster source and flux in the nozzle versus the running time for Ar gas.

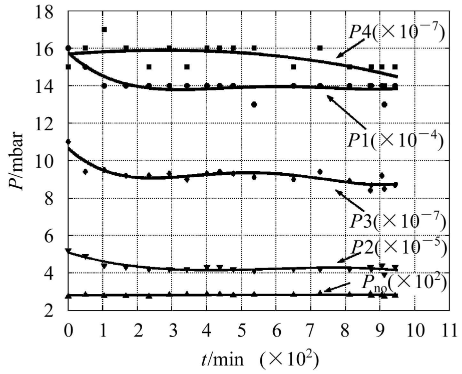

Fig. 6. Pressure in different chambers of the cluster source versus the running time for H_2 gas.

3 Conclusion

New test of hydrogen and argon gases are performed. The jet formation under different P_{no} and the attenuation of the jet caused by the collision with residual gas is studied. The maximum achievable H_2 target density is 1.75×10^{13} atoms/cm^3 which corresponds to a target thickness of 6.3×10^{12} atoms/cm^2 for HIRFL-CSR cluster target. The H_2 jet density achieved is higher than that of the ESR internal target, and is also better than the expected value of 1×10^{13}atoms/cm^3 for H_2. The results of long time running for H_2 and Ar cluster jets look promising. The jet intensity has no essential change during the test for H_2 and Ar.

References

1 XIA Jia-Wen, ZHAN Wen-Long, WEI Bao-Wen et al. Nucl. Instrum. Methods, 2002, **A488**: 11
2 CAI Xiao-Hong, YU De-Yang, CAO Zhu-Rong et al. Chinese Physics, 2004, **13**: 1679
3 CAI Xiao-Hong, LU Rong-Chun, SHAO Cao-Jie et al. Nucl. Instrum. Methods, 2005, **A555**: 15
4 Ekström C. Nuclear Physics, 1997, **A626**: 405c
5 Gruber A, Bourgeois W, Franzke B et al. Nucl. Instrum. Methods, 1989, **A282**: 87
6 LU Rong-Chun. Master Degree Thesis, Lanzhou: Institute of Modern Physics, Chinese Academy of Sciences, 2005, 49—52
7 Krämer A, Kritzer A, Reich H et al. Nucl. Instrum. Methods, 2001, **B174**: 205

HIRFL-CSR团簇靶的优化*

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摘要 为HIRFL-CSR团簇内靶设计加工了新的供气系统, 拆换了原有的喷嘴, 对氢气和氩气进行了新的实验, 获得了氢气和氩气的稳定团簇束, 解决了困扰团簇靶稳定运行的喷嘴堵塞问题. 获得的氢团簇束密度为1.75×10^{13}atoms/cm^3, 好于德国GSI内靶对氢束所达到的1×10^{13}atoms/cm^3. 研究了团簇束的衰减, 测量了氢束和氩束的有效靶厚, 研究了团簇靶系统对这两种工作气体的长期运行稳定性. 对氢和氩两种工作气体, 各级气压呈现了良好的稳定性, 说明在实验的时间范围内, 团簇靶运行稳定.

关键词 重离子储存环 内靶 团簇靶 原子束

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