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Performance of the detonation driven shock tube with a converging throat

ZHAO Wei , JIANG Zong-Lin , WANG Chao
(LHD ,Institute of Mechanics ,Chinese Academy of Sciences ,Beijing 100080 ,China)

Abstract:In order to increase the performance of the detonation driven shock tunnel , some converging throats are added in driver section near the main diaphragm. Experimental results indicate that this way can availably weaken the effect of Taylor rarefaction waves.

Key words:detonation ;detonation driver ;shock wave ;shock tube ;throat

增设收缩截面后的爆轰驱动激波管性能研究

赵 伟,姜宗林,王 超
(中国科学院力学研究所LHD开放实验室,北京 100080)

摘要:为提高前向爆轰驱动激波风洞的性能,采用在驱动段靠近主膜处增设一个收缩喉道的方法,以此来产生较为均匀的驱动气源。实验结果表明此方法有效地削弱了爆轰波后Taylor稀疏波的影响。

关 键 词:爆轰;爆轰驱动;激波;激波管;喉道
中图分类号:O381;V211.751 **文献标识码**:A

0 Introduction

The shock-tunnel with high driver performance is urgently needed in order to meet the requirement of the ground hypersonic vehicle experimental research on real gas effects ,reentry phenomena and supersonic combustion[1,2]. There are two kinds of main facilities to generate high enthalpy test flow ,free piston[3] and detonation driver[4].

In recent years ,detonation driven shock tunnel has been more arrestive because of its low operation cost and simple configuration besides the high driver performance to generate

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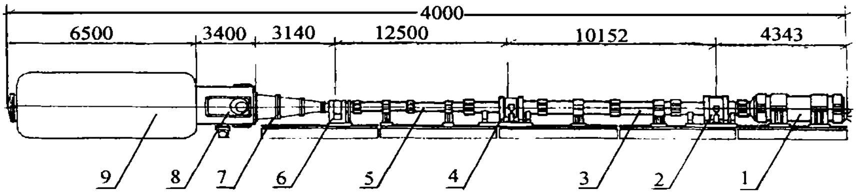
Biography:ZHAO Wei(1966 -) ,male ,born in Kashi ,Xinjiang Province ,associate Professor in LHD , Institute of Mechanics ,CAS.

high enthalpy test flows. Although detonation driver was first studied by Bird[5], Coates[6] and Yu[7] during 1956～1962, Yu[8] realized the actual upstream mode of detonation driven shock tunnel by adding a damping section at the end of driver section, and applied it to produce test flow under high initial pressure.

After a detonation test tube with inner diameter 100mm was finished in LHD at 1990, some groundwork experiments were conducted on it. According to the experimental results[9], a large detonation driven shock tunnel JF 10 (Fig. 1) was set up in 1996, with driver section 150mm in diameter and driven section 100mm in diameter. In Germany, a new detonation driver section with 150mm in diameter was naturalized in TH2 shock tunnel in Aachen Shock Tube Laboratory till 1998[10].

Not only upstream mode (Fig. 2a) of detonation driven shock tunnel was calibrated but also downstream mode (Fig. 2b) was attempted. The results indicated that the attenuation of the incident shock wave was weak and the driving flow was uniform under the upstream mode, it adapts to generate high Reynolds test flow. However, the driving pressure is only 40 % of C-J pressure and the kinetic energy of driving flow is waste, so the performance to generate high enthalpy is lower than that of the downstream mode. There is also some disadvantage for downstream mode, the attenuation of the incident shock wave is strong due to Taylor rarefaction waves[1].

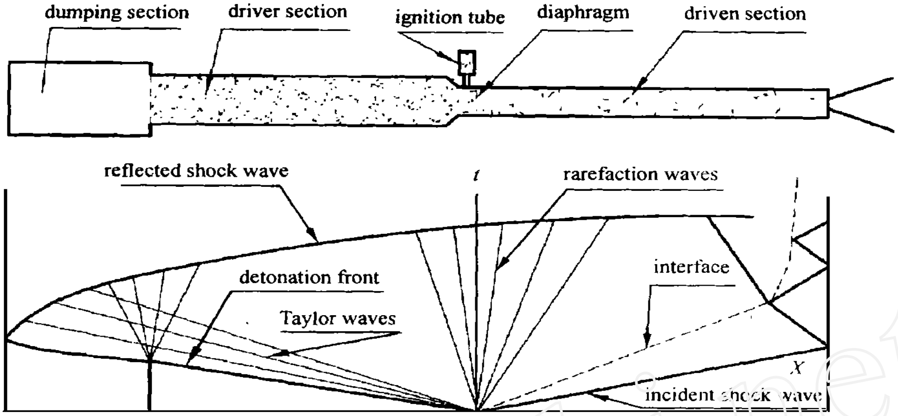


1 dumping section
2 fastening machine
3 driver section
4 fastening machine
5 driven section
6 fastening machine
7 nozzle
8 test section
9 vacuum receptacle

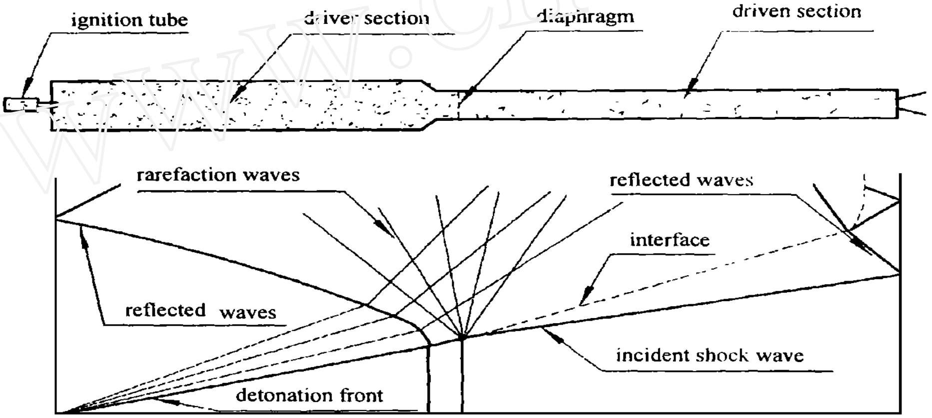
Fig. 1　Sketch of JF 10 detonation driven shock tunnel

图 1　JF 10 爆轰驱动激波风洞结构简图

In order to minimize the effect of the Taylor rarefaction waves in downstream mode, a converging section is used in JF 10 detonation driven shock tunnel. This way is obvious and effective but also limited. Other way to add a driver section filling high pressure helium to the end of detonation section was also applied by the Lab of GASL in USA[11]. By means of the strong incident shock wave produced by high pressure helium, overdriven or sub-critical detonation waves can be obtained, but a mass of helium is not economical, new methods must be investigated continually. Jiang[12] adviced to add a cavity ring near the primary diaphragm in detonation driver section, which will be discussed in another paper. The other way which focus on this paper is adding a converging throat near the diaphragm in detonation driver sec-



(a) upstream mode



(b) downstream mode

Fig. 2 Wave charts of two kinds of mode of JF 10 detonation driven shock tunnel

图2 JF 10爆轰驱动激波风洞两种运行模式波图

tion.

1 Experimental description

In order to verify the effect of the new idea ,experiments were conducted on the new facilities ,(Fig. 3) which is made of stainless steel ,driven section 60mm in inner diameter ,7m in length ,driver section 90mm in inner diameter ,4m in length. Some other tubes were also used which are changeable and replaceable. Two kinds of converging throat are used to compare the effect ,one throat is 40mm in diameter ,and the other is 30mm in diameter.

Iron diaphragm 1mm thick which is cross fluted of 0. 2mm valid thick seems fine when it was opened ,but when initial pressure of the mixture increase up to 2 MPa ,steel diaphragm

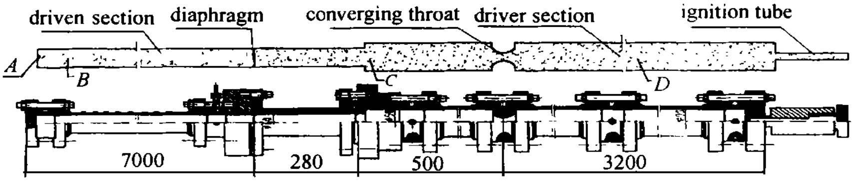


Fig. 3　Configuration of new detonation driven shock tube

图 3　新型爆轰驱动激波管结构示意图

is hard to be used as primary diaphragm. Steel diaphragm was often cut more or less because the load on the diaphragm by the upstream detonation front is too fast and strong. Some ways have been tried to solve the problem.

Double sub-critical sonic nozzles are applied to fill the hydrogen and oxygen, by which two kinds of gasses are filled into the driver section simultaneity. Result tested by chromatogram indicated that the mixture is uniform enough to be applied in the detonation experiments.

Ignition tube has a good performance to initiate the mixture, it can form detonation very fast in driver section, and its construction is simple. This way has been applied in J F^{10} detonation driven shock tunnel successfully, and was also adopted by Aachen Shock Tube Lab.

As downstream mode is mainly used to generate high enthalpy test flow, the speed of incident shock wave is very fast, which Mach number is more than 10 and higher. In order to test the speed accurately, the SC25 measure system which frequency can achieves 1.25MHz and ionization probes were adopted,

All the tests was done under the condition which the initial pressure of mixture is 0.5 MPa, initial pressure of air in driven section is 0.0013～0.027MPa.

2　Experimental results

The ionization signals shown in Fig. 4 can be used to measure the shock wave speed. Pressure curve recorded at position *D* shown in Fig. 5, after the detonation front propagate through the test point, it reflected between the throat and the lid of driver section up and down, and decayed gradually. Upon a certain extent, detonation waves will focus on the throat, and form an overdriven detonation in a short time and short distance, which will be helpful to produce a constant driving flow near the primary diaphragm. Fig. 6 shows the pressure curve, which recorded at position *C* near the diaphragm. Fig. 6a is recorded under the throat 30mm in diameter, and Fig. 6b is under the throat 40mm in diameter. It is not obvious different between them, maybe later effect is better. However, the decay of detonation front induced by the Taylor wave relaxes obviously.

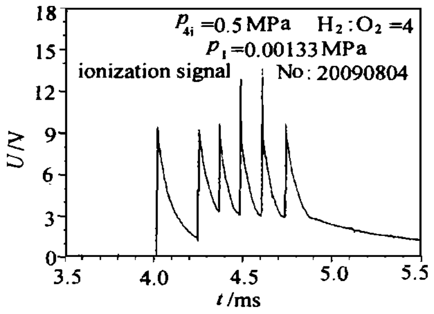


Fig. 4 Ionization signals recorded by PC

图4 微机采集的电离测速信号

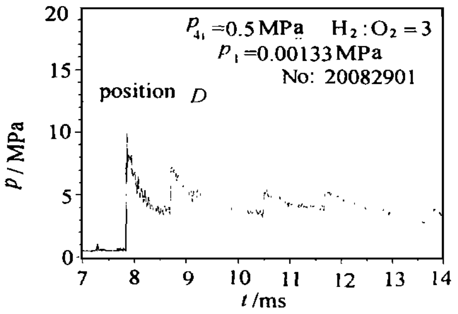
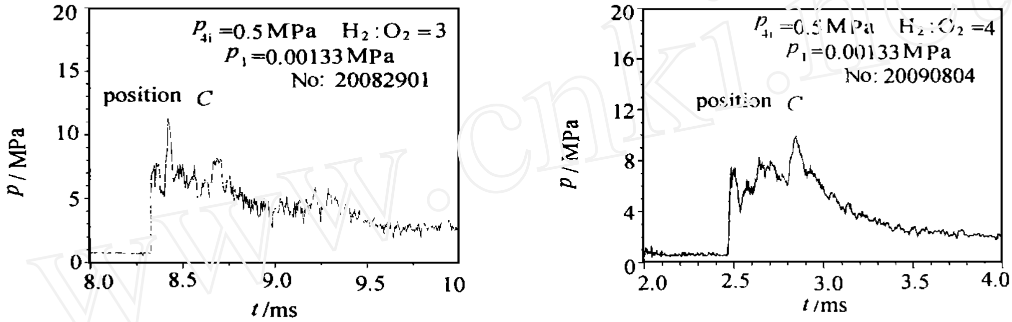


Fig. 5 Pressure history recorded at position D

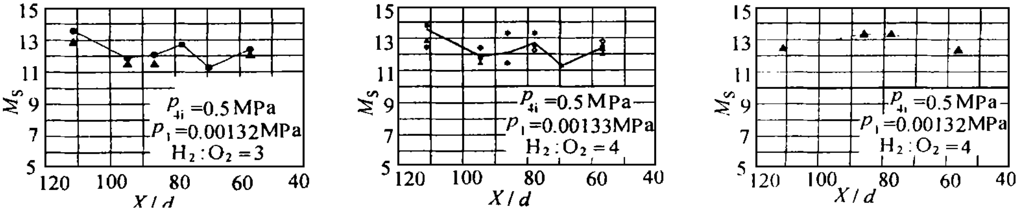
图5 测点 D 记录的压力曲线



(a) Φ30mm (b) Φ40mm

Fig. 6 Pressure histories recorded at position C near the primary diaphragm

图6 驱动段主膜附近 C 点测得的压力曲线



(a) Φ30mm (b) Φ40mm (c) no throat

Fig. 7 Attenuation of the incident shock wave along the shock tube

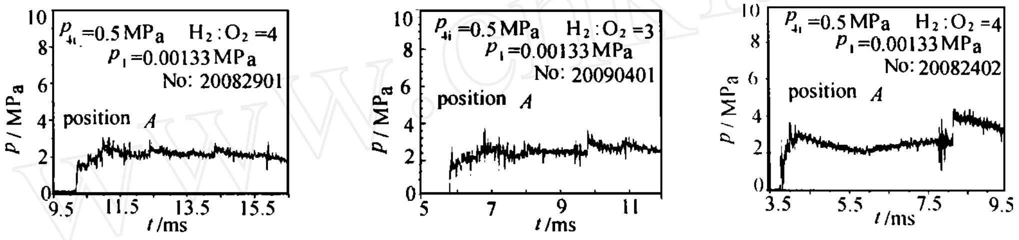
图7 三种状态下入射激波沿激波管的衰减分布

Attenuation of the incident shock wave along the shock tube is shown in Fig. 7 ,throats are different between 7(a) and 7(b) ,and no converging throat is used in 7(c) . It is abnormal to compare the results of 7(a) and 7(b) with conventional shock tube ,the speed decreases in some parts ,but it increases near the end of shock tube ,which related to the condition of driving flow in driver section with converging throat. In Fig. 7 ,the speed accelerates at beginning ,but decreases at last. However ,the driving capability to produce strong shock wave is more perfect after the throat is used.

The condition at the end of shock tube after the reflection of incident shock wave is regarded as the stagnation gasses source to shock tunnel ,three stagnation pressure histories are shown in Fig. 8 ,which enthalpy is about 23 MJ/ kg. They are all recorded at the cover of shock tube ,unlike Fig. 8(a) and Fi. 8(b) ,no throat used in Fig. 8(c) . The pressure histories shown in Fig. 9 are recorded at position *B* which is 500mm distance to the cover ,and the conditions are the same as Fig. 8.

Stagnation pressure fluctuates in Fig. 8a and Fig. 8b , but no same phenomena responses in Fig. 9a and Fig. 9b. Analyzing the flow in shock tube ,the fluctuating are caused by the reflection of shock wave with the interface.

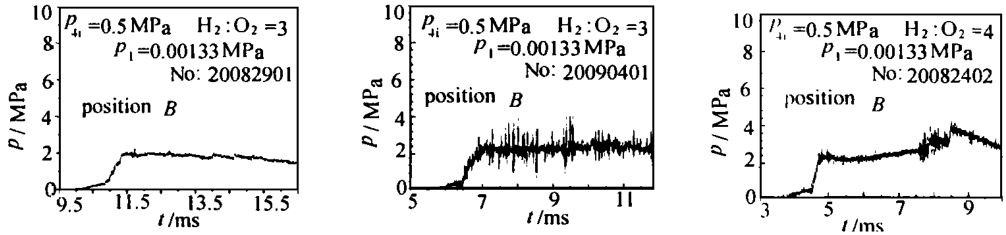
Pressure decays obviously in Fig. 8c ,and no uniform history shown in Fig. 9c. Although no essential difference between Fig. 8a and Fig. 8b in the main ,some conclusion can be speculated by the other curves shown in Fig. 9 because the distance is very close between two tested positions *A* and *B* (reference Fig. 3) . As the curve of Fig. 9b seems more flat ,the effect of throat 40mm in diameter is better than that of throat 30mm in diameter.



(a) Φ30mm　　(b) Φ40mm　　(c) no throat

Fig. 8　Stagnation pressure histories recorded at Fig. 3 position A

图 8　在图 3 测点 *A* 测得的三种状态下驻室压力曲线



(a) Φ30mm　　(b) Φ40mm　　(c) no throat

Fig. 9　Pressure histories recorded at Fig. 3 position B

图 9　在图 3 的测点 *B* 测得的三种状态下驻室压力曲线

By means of reference Fig. 7 ,the shock wave strength (*M*s) with the throat is higher than that of without the throat. By the reference of Fig. 9 ,the constant pressure time is longer than that of without the throat. In conclusion ,not only the capability but also the quality is better when the throats are used.

3　Conclusion

With the throat near the main diaphragm in driver section ,it is effective to weaken the effect of Taylor rarefaction waves in detonation driven tube/ tunnel. As throat is simple in structure to be added in tube ,this way is available.

The disadvantage of the downstream mode can be overcome by this way ,and this mode could be practically applied in shock tunnel ,which can be used to generate the high enthalpy test flow with more constant parameters.

The exiguous effect between different throat should be investigated by means of CFD , including throat shape and size. The optimal position to add the throat should also be taken into account.

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