merits of some of the brakes described. Practical tests have certainly proved the superiority of Air Brakes over all others. These brakes may be divided into two systems—Pressure and Vacuum—further, each system may be divided into three classes, as under:—

PRESSURE.

Class 1.—Those which are non-automatic, as described above. Class 2.—Those which require pressures to be maintained on both sides of the piston to keep brakes off.—(Steel and McInnes, Hanscom and List.) Class 3.—Those in which the air for applying them is stored apart from the brake cylinder, in a reservoir by one or more valves.—(Westinghouse.)

VACUUM.

Class 1.—Eames' Non-Automatic type. Class 2.—Those which require a vacuum on both sides of the brake piston to keep the brakes off.—(Vacuum Company's.) Class 3.—Those in which the reservoir is kept exhausted, and its communication with the brake cylinder controlled by one or more valves. (Hardy's.)

Class 3 of Pressure Brakes may be further divided as follows:—First, those requiring all the air in the train pipe to be exhausted to fully apply the brakes, as Selfe's. Second, those requiring only a portion to do this work, as the Westinghouse and Humphrey. Third, those which graduate the brakes both On and Off, as in the Selfe and Humphrey; and, Fourth, those which graduate On only, as in the Westinghouse.

The two best automatic brakes *in use* are, propably, the Westinghouse, Class 3, which graduates the brakes On only, but applies them fully upon the reduction of a percentage of the pressure in the train pipe; and the Vacuum Company's, Class 2, which graduates the brakes both On and Off, but requires the *complete destruction* of the vacuum in the train pipe, and that portion of the cylinder in communication with it, to fully apply the brakes. The question of commercial superiority respecting the above two brakes is still a debatable one, and the respective merits of rival brakes are generally sought to be obtained by tests which are carried out by fitting each brake to a different train. True results would unquestionably be obtained if one train were used for all the brakes.

The author will devote the remainder of the paper to a brief analysis of some of the brakes above mentioned. Taking first the Westinghouse and Vacuum Company's system, and assuming each brake to be fitted to a train of six carriages, the train pipe will be approximately 250ft. long. The Westinghouse train pipe is taken at 1in. diameter, the brake cylinder 10in. diameter, and the maxium pressure in it 60lb. per square inch. The vacuum train pipe is taken at 2 inches diameter; the the brake cylinder $23\frac{11}{32}$in. diameter, and the effective brake pressure 11 lb. per square inch. The contents of the reserviors under each carriage, in both cases, are five times the contents of that part of the brake cylinder moved through by the brake piston, the latter having 6in. stroke. To apply the Westinghouse Brake *fully* (graduating on only) one-fifth of the air at a pressure of 75 lb. per square inch, has to be exhausted from the train pipe. Therefore, the total amount of air, brought down to atmospheric pressure, and used in this operation is $9\frac{1}{2}$ cub. ft.

To apply the vacuum brake *fully*, the partial vacuum in the train pipe, together with those portions of the six brake cylinders in free communication with it, have to be completely destroyed. This necessitates the use of $11\frac{1}{4}$ cubic feet of air at atmospheric pressure, or $1\frac{3}{4}$ cubic feet more than required by the Westinghouse. The whole of this $11\frac{1}{4}$ cubic feet is admitted to the train pipe at the engine during ordinary working, while, with the Westinghouse, only $1\frac{1}{3}$ cubic feet are exhausted at the engine, and this, too, at a high pressure. The balance of the $9\frac{1}{2}$ cubic feet of air used in the Westinghouse is supplied from a store in close proximity to the brake cylinder, and this renders the action of the brake speedy. The action of these brakes in graduating off will briefly be considered. It is assumed that the above train is moving at 60 miles per hour when the brakes are applied. The cylinder pressure, upon the first application, is assumed at 60 lb. per square inch; but as about one-third of the pressure necessary to skid the wheels at 60 miles per hour will skid them at 7, only about 20lb is needed when this low speed is attained. This low pressure is reached by five separate applications of the brake, which represent a total consumption of about 36 cubic feet of air brought to atmospheric pressure. From the above it will appear that to apply the Westinghouse Brake once, less air is used than with the vacuum. But to effect a stop by graduating as noted above, $24\frac{3}{4}$ cubic feet more air would be used. Although trains should be brought to rest in the manner indicated, it by no means follows that they are. The author has very often watched the gauges placed in the carriages on our suburban lines while the brakes were being applied, and in almost every case the pressure in the train pipe was first slightly reduced, then followed up by further reductions as required, until the train stopped. The stoppage was thus brought about by one application of the brake, and when used in this manner the Westinghouse is far more economical than the vacuum.

Subjecting the Hanscom Brake to the foregoing conditions, we find that with a pressure of 40lb. per square inch the brake cylinder will require to be $12\frac{1}{2}$in. in diameter. To *fully* apply the brake, all the air in one of the train pipes, and those portions of the cylinders in free communication with it—amounting to 12·6 cubic feet—has to be discharged. Although the brake can be released by again restoring the original pressure in that train pipe, the brake blocks are not removed from the wheels, and it is necessary, before the piston will move back, to reduce the pressure behind it; but as the automatic valve is loaded to about 15lb. per square inch, no air can leave the brake cylinder without it exceeds the pressure in the brakes on train pipe by at least that amount. Therefore, to release the brakes *fully*, and remove the blocks from the wheels, it is necessary to discharge from the cylinder the air that has been employed in applying the brakes; which with that reduced from the train pipe, amounts to 10·4 or a total of 23 cub. ft. used in one application. Like the vacuum, the amount of air used in applying the brake once represents the amount necessary for any number of graduations at reducing pressures. To summarize: it is found that the relative quantities of air in a distinct application for each of the above brakes when *properly* graduating off is—Vacuum, 11 cubic feet; Hanscom, 23 cubic feet; Westinghouse, 36 cubic feet, or 9½ cubic feet when making the complete application through a series of five or more separate advancing pressures.

None of the air brakes described fulfil the conditions laid down in the early part of the paper, without a second train pipe. If a second train pipe were added to the Steel McInnes brake, provision would have to be made for withdrawing the blocks from the wheels, a valve has been invented for this purpose which allows the air used in the brake cylinder to be exhausted. With the additional train pipe and this valve we have the Hanscom brake. To apply a second train pipe to the brake of the Vacuum Company it would be necessary to provide means for removing the block from the wheels, such as a weight on the piston, or by maintaining a vacuum of lesser intensity in the second train pipe, or by extending the piston rod and making it of sufficient area to perform the work. A second train pipe can be easily applied to the Westinghouse brake and certainly add materially to its safety. The action of the Vacuum Company's brake, when the vacuum in the train pipe was slowly destroyed, the cylinders would also simultaneously be exhausted. This brake is therefore a more suitable one for goods trains than that of the Westinghouse Company, which, if their instructions are obeyed, cannot be applied with a pressure of less than 32·4lb., notwithstanding the following statement which appears in their book of 1889, page 20—" By simply regulating the reduction of pressure in the train pipe, and causing the motion of the piston and graduating valve to be repeated, the driver can gradually introduce any desirable pressure into the brake cylinder from zero up to full power." It is questionable whether the unequal friction of the triple valves will permit of them all being moved down simultaneously. In making emergency stops, with a brake pressure not exceeding weight of vehicle, the brake of the Vacuum Company is quite equal to that of the Westinghouse, but the action of the latter, as measured by the slideometer, is steader, owing no doubt to the smaller percentage of air exhausted to operate the quick-action triple valve, and the light pressure from the train pipe striking the brake piston first.

Both types are equal to the braking of a few couplings while making such a stop, but as far as its action is concerned the Vacuum Company's brake is superior to that of the Westinghouse. But the bulkiness of the apparatus, the stuffing box, or its equivalent for the piston rod, the rubber pipe connections to the brake cylinders, and the diaphragms on the quick action, release, and guard's van valves, will not be looked upon with favor by those who have to keep it in working order. The statement that ejectors are large steam users appears to have some foundation. If they are not, it would pay the Vacuum Company to supply some reliable data respecting their capabilities. Further, ice and dust will give more trouble to a vacuum than a pressure brake, and in this the Selfe and Humphrey brakes are similar. The principal difference lies in the former requiring the complete destruction of the pressure in the train pipe before the brake is fully applied, while the latter requires only a percentage according to the relative areas of the pistons in the pressure registering and graduating off valve. The constant pressure reservoir, working with one train pipe, affords another material departure from the Selfe brake. With both brakes, leaky brake cylinders are replenished by the adjusting properties of their respective valves. Not so the

Westinghouse or Vacuum, as with the former its brake cylinder pressure does not influence the triple valves; and in the latter a leaky brake piston not only destroys its own efficiency, but lessens that of the others. Since inventing the valve illustrated on Plate VIII, Fig. 1, the author's knowledge of railway brakes has been considerably enlarged, and his opinion somewhat changed. The superiority of a valve in which the pressures on the sides of its piston are unequal for an infinitesimal period of time, is obvious upon reflection. In the light of this and other considerations, Mr. Humphrey has designed a graduating off valve, which, with the addition of a second train pipe, can be used in connection with the Westinghouse triple valve in all its forms. Plate VIII, Fig. 2 shows it in connection with an ordinary triple valve, and as such is termed an expansion regulating valve. The combination consists of a triple valve placed horizontally, attached vertically to a small cylinder similar in form to itself. This cylinder contains a graduating off piston and small slide valve connected together as in the triple valve. Communicating with the lower side of this piston is a small second train pipe. While the pressure in this train pipe is greater than the pressure above the piston, the slide valve is kept over a second exhaust port. The valve operates as follows:—The driver, before applying the brakes, admits the required pressure into the second train pipe, which forces up the graduating off piston and slide, closing the second exhaust. After having applied the brake in the ordinary way the triple valve is brought to the release position, which establishes a communication between the brake cylinder and the top of the graduating off piston. By simply regulating the pressure under this piston, by means of the second train pipe, the brakes can be graduated off in a manner practically perfect. When it is remembered that, under certain conditions, the present Westinghouse brake is not safe without a second train pipe, and its necessary check valves, which, in some countries, have been adopted—(See "Proceedings," Vol. II., page 147)—

the value of the above addition to the triple valve is apparent. It supplies the all-important advantage of being able to graduate off.

In conclusion, the author acknowledges his thanks to Mr. Humphrey for the assistance received in the preparation of this paper.

DISCUSSION.

MR. W. D. CRUICKSHANK, in opening the discussion, said that he had listened to the reading of the paper with a considerable amount of pleasure. The method proposed by the author of comparing the Westinghouse and Vacuum Coy's. brakes was misleading, as any person who understood the practical working of brakes must be aware of the fact that they were not fully applied once in five hundred times, and therefore the figures given were of little value. He did not consider it just or reasonable to base calculations on any figures but those obtained under ordinary average working conditions. When a full application of the brake was made it would be in the case of an emergency stop, and under such circumstances economy was a secondary consideration, the primary one being one of life or death.

One advantage the Vacuum Coy.'s brake had over the Westinghouse, was that with a train having two locomotives both of them could apply the brakes, but with the Westinghouse this could not be done. In connection with this point the railway authorities had acted very wisely in introducing more powerful locomotives on the mountain trains, one being able to do the work that had previously required two of the smaller class.