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Abstract

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Keywords

Pneumatic conveyor, Combine, Seed

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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INJECTOR FEEDER FOR PLOT COMBINE PNEUMATIC CONVEYOR

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ABSTRACT

The pneumatic grain conveyor on a plot combine was evaluated and its crosstube grain injector redesigned to increase material throughput to a rate that would avoid plugging during operation in high-moisture corn. The new design allowed a throughput of 77 kg/min (169 lb/min) of high-moisture corn during tests.

KEYWORDS. Pneumatic conveyor, Combine, Seed.

INTRODUCTION

Starting in about 1981, the popularity of dilute-phase pneumatic conveyor systems for grain, including seed grain, rapidly increased (Noyes and Pfeiffer, 1985). Manufacturers of plot combines for seed research plots find pneumatic conveyors superior to conventional combine conveying methods because pneumatic tubing can be easily routed around the combine and because pneumatic conveyors allow rapid, complete cleanout. Professionals in the seed industry require combines that will harvest plots without cross-contamination of seed between plots. To achieve this, it is necessary to eliminate potential dead spots where seed can hang up in the machine and to provide complete cleanout through the machine; a pneumatic conveyor provides such a complete cleanout feature. The disadvantage of increased power requirements with pneumatic conveyors is not considered a major problem on these specialized combines. Moreover, an acceptable level of seed damage can be attained through proper design.

PLOT COMBINE CONVEYING SYSTEM

Almaco, a plot combine manufacturer in Nevada, Iowa, has been using a low-pressure, dilute-phase, pneumatic conveyor on their plot combines since 1974. This conveyor takes seed exiting the cleaning system, conveys it to a collection point near the operator, and provides complete cleanout between plots. The system, unconventional in nature, uses a centrifugal fan as an air mover, a crosstube venturi injector as a feeder mechanism, and a cyclone separator.

with a weigh hopper and a moisture cell mounted directly below the separator.

The fan is located on the right side of the combine and its outlet is directed at a downward angle towards the rear underside (fig. 1). Tubing is steel with a 14-gauge wall \times 127-mm (5-in.) outside diameter. Downstream 750 mm (30 in.) from the fan, a 90°, 203-mm (8-in.) radius elbow directs air horizontally into the crosstube injector. The 860-mm (34-in.) long crosstube is welded to the exit throat of the combine cleaning system feeding the injector at a pitch of 35° from vertical. On the exit end of the feeder crosstube, a 90°, 203-mm (8-in.) radius elbow directs flow vertically up the left side of the combine. Another identical elbow is placed 2400 mm (95 in.) up from the last elbow, directing flow 1200 mm (47 in.) horizontally across the machine to the cyclone separator.

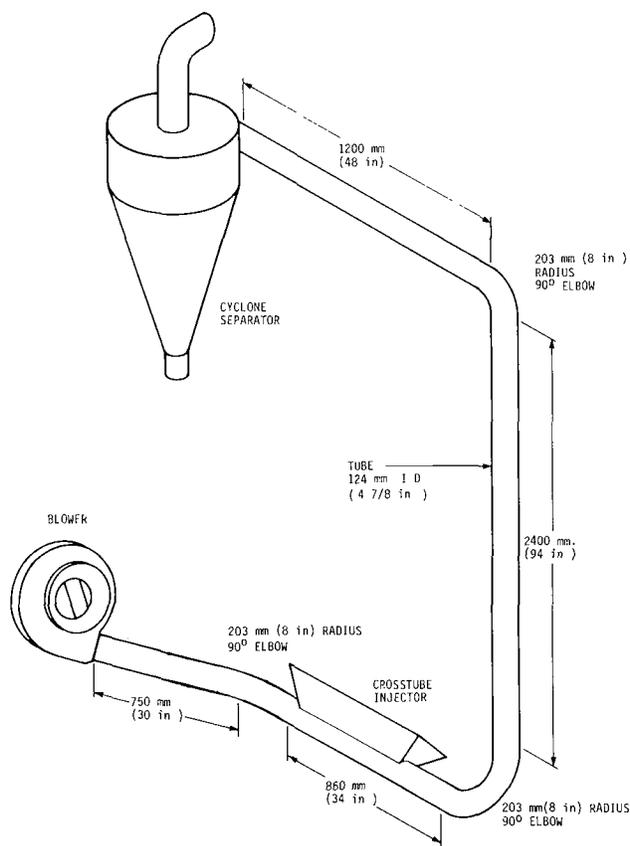


Figure 1—Almaco plot combine conveying system layout.

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PROBLEM DESCRIPTION

This combine conveying system must handle a variety of small grains as well as soybeans and corn. To accommodate these different crops, fan speed is changed by means of a variable-pitch sheave. This adjustment allows the pneumatic system to handle the various crops effectively, with one exception: high moisture corn. This crop presents a problem for three reasons: 1) high mass flow rates; 2) high sliding friction levels; and 3) low flowability due to moisture (Noyes and Pfeiffer, 1985). When a certain system throughput is exceeded, corn backs up and plugs the vertical section and elbow on the crosstube exit. The operator must then shut down the machine, release the pipe coupling connecting the elbow to the vertical section of pipe (on the exit side of crosstube), and clean out the grain by hand. The plugging problem was thought to be due to inadequate performance of the crosstube injector. The objective of this project was to solve the problem of high-moisture corn plugging in the pneumatic conveyor by analyzing the system and by making necessary modifications to increase allowable material throughput to a level above the minimum harvest rate while maintaining acceptable manufacturing cost and grain damage levels.

PROCEDURE

Analysis of the system consisted of lab tests to determine performance and efficiency of the centrifugal fan and instrumented tests of the pneumatic system. Modifications were then made to the design of the crosstube injector.

CENTRIFUGAL FAN

The pneumatic system fan is manufactured by Almaco (fig. 2). The impeller is 381 mm (15 in.) in diameter and has six radial blades. It is belt-driven from the winnowing blower on a 25.4-mm (1-in.) diameter shaft at 2800 to 3200 r/min. Two 178-mm (7-in.) diameter holes on the sides of the fan casing serve as air intakes. The outer intake hole is guarded for operator protection. Because of inaccessibility, the inside opening (driven side) is not guarded. The fan outlet is 127 mm (5 in.) in diameter. The fan was tested in the Iowa State University Agricultural and Biosystems Engineering Department's fan test chamber, which was built in accordance with AMCA Standard 210-74 and ASHRAE Standard 51-75 (AMCA, 1975). Results are shown in figures 3 and 4. See Meester (1989) for a complete description of the test procedure.

CROSSTUBE INJECTOR

The crosstube injector feeder mechanism is used to introduce grain into the airstream. It is gravity fed from a belt conveyor traveling 5.5 m/s (1083 ft/min) that carries grain from the combine's cleaning system and controls feedrate (fig. 5). The airstream is controlled with baffles. In the original design, open areas totaling 600 cm² (93 in.²) were incorporated to allow gravity-feeding of grain. This large opening produced large flow and pressure losses in the system. The airflow out of this opening also interfered with winnowing air used to clean the grain.

Because of the necessary lateral orientation of the crosstube on the combine, overall length of the injector

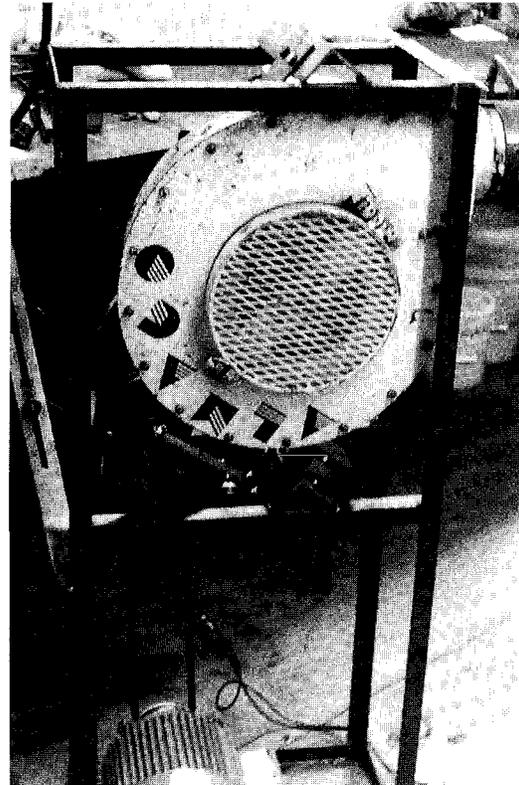


Figure 2—Almaco centrifugal fan on test stand.

plus two elbows must remain less than the maximum combine width of 1.3 m (51 in.). This constraint limits the length of pipe between the material entry point and the first downstream elbow. Although Noyes and Pfeiffer (1985) recommend at least 3 m (9.8 ft) of straight pipe for this length to allow for material acceleration, the length of pipe used on this combine is limited to 0.15 m (5.9 in.). This constraint also mandates use of small-radius elbows. Pos and Lampman (1972) recommend a radius of curvature for bends of at least six to eight pipe diameters to minimize pressure losses. Elbows of 1.6 to 1.8 pipe diameters are typically used. As can be seen here, guidelines normally

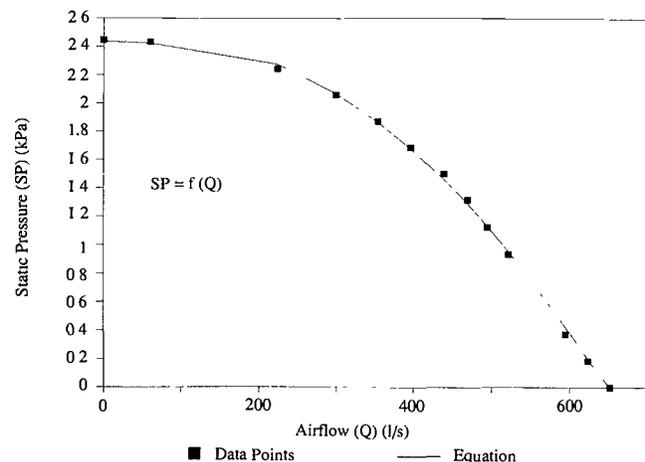


Figure 3—Almaco centrifugal fan performance at 3200 r/min.

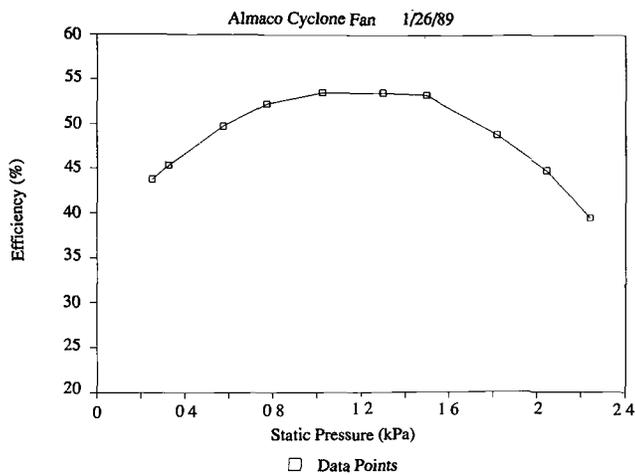


Figure 4—Almaco centrifugal fan mechanical efficiency at 3200 r/min.

used with pneumatic conveyors are impossible to adhere to without changing the lateral orientation of the crosstube.

CROSSTUBE TESTING PROCEDURE

A basis for comparisons of injectors was established prior to testing. Typical plot harvesting rates and yields were considered, and a rate of 70 kg/min (154 lb/min) for corn was set as a minimum. Subsequently, a test stand was set up to compare throughput rates and pressure losses of different injectors.

The complete conveying system was constructed apart from the combine. To simulate feeding corn into the injector, a hopper was placed above it. Corn was hand fed into the hopper, which had a full-width outlet covering the length of the injector. Several trials of corn conveyance were performed on each crosstube. Dry (14% moisture) corn of unknown genotype was used. The maximum rate obtainable without plugging the system was recorded as the throughput. Replicated tests were not conducted. Static pressure was measured on the intake and on the exit side of each injector. Velocity pressure on the exit side was determined by use of a 17-point pitot-tube traverse. Airflow values were calculated from these pressures. All pressure readings were made with no grain in the system. Intake velocity pressures were calculated from flow rates obtained from the fan curve. These tests provided a basis for comparing the performances of different injectors. See Meester (1989) for complete test data.

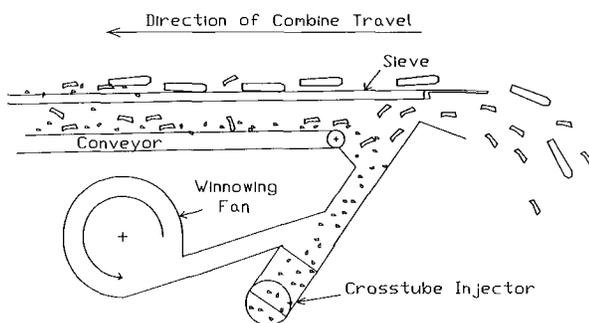


Figure 5—Cross-sectional view of cleaning and conveying system.

TEST RESULTS

Each crosstube injector described here was tested at a fan speed of 3200 r/min. Data for the material throughput rate (S), total pressure (TP), static pressure (SP), velocity pressure (VP), and the percent of total pressure losses are presented for each injector, along with a brief discussion of its performance. Corn quality changes during conveying were not measured.

CROSSTUBE NO. 1

Figure 6 shows Crosstube No. 1, the original injector used on the plot combines. Dimensions marked with an asterisk on this crosstube are basic length restraints imposed on all crosstubes. A baffle restricting the air inlet of the crosstube was installed to provide a venturi effect to lower static pressure on the inlet side of the injector. A second control baffle was placed midway across the length of the injector to provide additional control. The 127-mm (5-in.) cross-sectional grain passage area of this injector is relatively large. The system plugs at corn input rates exceeding 55 kg/min (121 lb/min).

CROSSTUBE NO. 2

The first major change involved reducing injector opening width from 127 mm (5 in.) to 51 mm (2 in.), as shown in figure 7. The three internal baffles installed were staggered in deflection angle, airstream depth, and lateral position. Locations and orientations for these baffles were determined experimentally with only air passing through the tube. The pressure losses were reduced and the material throughput was increased. But the difficulty of manufacturing and installing odd-shaped baffles was a major drawback.

CROSSTUBE NO. 3

An attempt was made with this crosstube to maintain better control of the airstream in a simple-to-build design extending the sides of the injector body farther into the tube while keeping the same 51-mm (2-in.) throat width (fig. 8). This design provided results comparable to those of Crosstube No. 2 but with greatly simplified manufacturing.

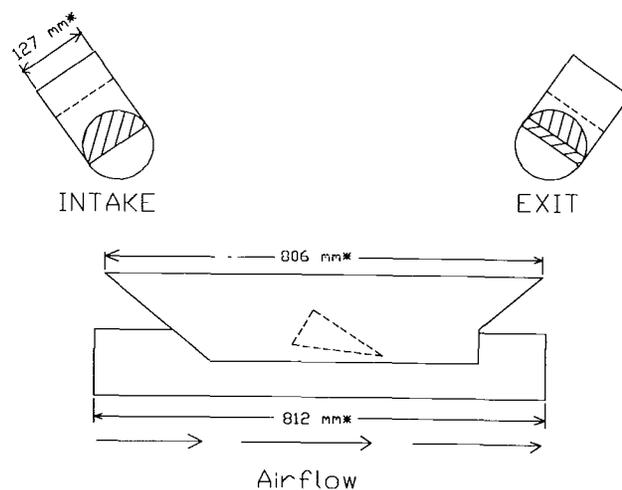


Figure 6—Crosstube No. 1.

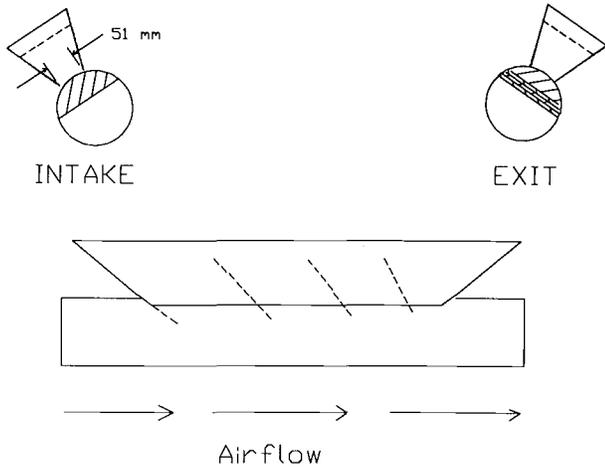


Figure 7—Crosstube No. 2.

CROSSTUBE NO. 4

High back pressure levels were noted during testing of all previous tubes while grain was fed into them. This increased pressure caused grain to rebound out of the open tail section and to re-enter in the forward sections of the tube or to be blown completely out of the hopper. Figure 9 illustrates a design providing a blowback aperture to relieve this static pressure by extending the tube 127 mm (5 in.) on the exit side. This design exceeded maximum crosstube length, and for this reason complete data on the performance were not recorded. However, testing of this design showed the value of the pressure relief feature. Static pressure in this aperture ranged from negative to positive values as great as 0.75 kPa (3 in W.C.); the amount of grain being conveyed also varied. The blowback aperture incorporated into this design helped reduce the amount of seed being blown out of the tail section of the injector.

CROSSTUBE NO. 5

With the previous information in mind, we built another crosstube incorporating a blowback aperture as well as the extended sides of the previous crosstubes (fig. 10). A

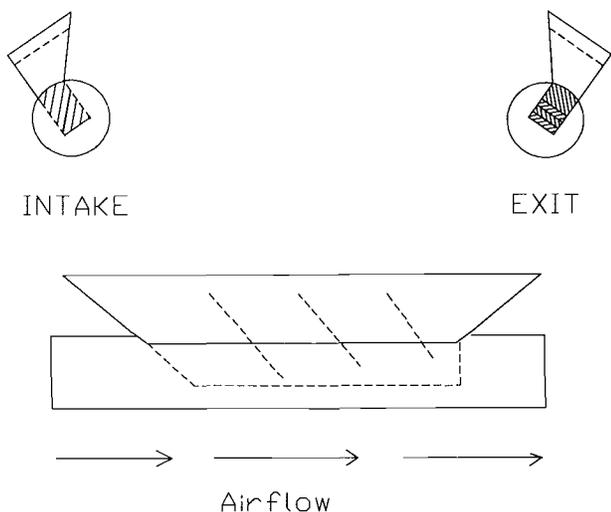


Figure 8—Crosstube No. 3.

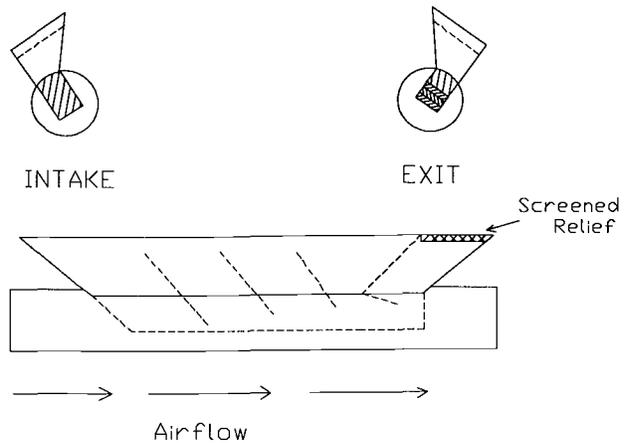


Figure 9—Crosstube No. 4.

compartment on one side of the injector was sealed off by placing a 90° bend on one of the sides of the inserted injector and extending it to the inside face of the tube. A small screen was placed over the opening at the tail of the compartment to prevent seed from being trapped. A hole and a screen were also placed in the tube to relieve air pressure in the compartment. The screen prevented trash entry from outside when there was negative pressure in the compartment. During testing of Crosstubes 5 and 6, pressure readings on the exit side were taken at a point 1.5 m (5 ft) downstream from the previous point.

CROSSTUBE NO. 6

Figure 11 (Crosstube No. 6) is similar to figure 10 (Crosstube 5) except for one change. The leading venturi baffle was formed with a rounded face to reduce airstream turbulence. This reduced pressure losses but failed to improve throughput rate of the crosstube. One possible explanation is that a reduction in the amount of turbulence made it more difficult for grain to enter the airstream.

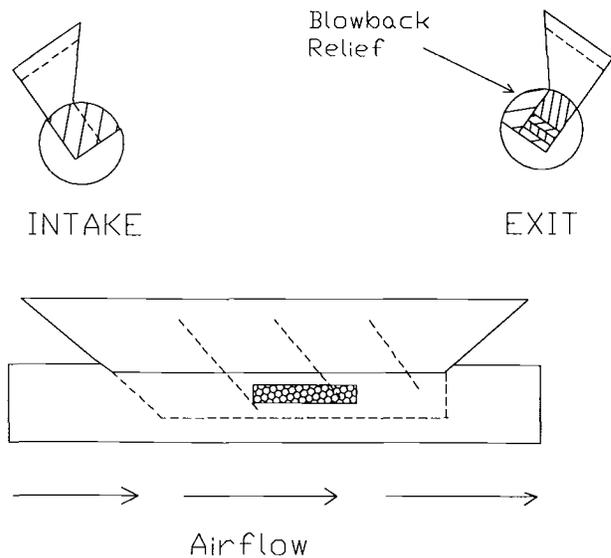
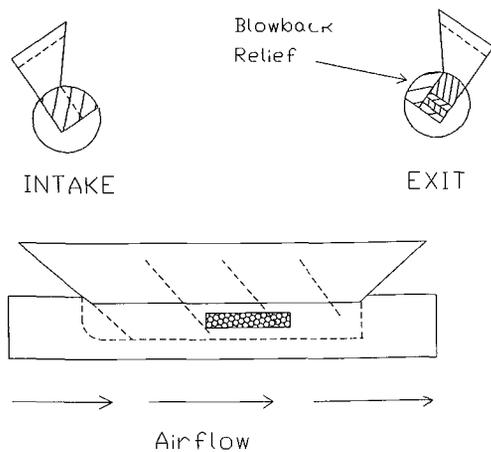


Figure 10—Crosstube No. 5.



TP=2.25 kPa (9.04 in W.C.)	TP=1.11 kPa (4.46 in W.C.)
SP=1.76 kPa (7.07 in W.C.)	SP=0.28 kPa (1.13 in W.C.)
VP=0.49 kPa (1.97 in W.C.)	VP=0.83 kPa (3.34 in W.C.)

Total pressure loss: 50.5%

Throughput: 68 kg/min (150 lb/min)

Figure 11-Crosstube No. 6.

DISCUSSION

Only Crosstube No. 5, with a throughput of 77 kg/min (169 lb/min), exceeded the specified 70-kg/min (154-lb/min) minimum design handling rate. With Crosstube No. 5, air velocity just downstream from the pickup point was 6994 ft/min (35.5 m/s), as calculated from the measured velocity pressures. At the observed throughput, the solids-to-air ratio was 2.5.

Crosstube No. 5 was selected and placed in production. This required no change in system layout on the combine. A design of this type may be applicable in other applications having a long narrow intake, limited space, and adequate fan power.

Some alternatives to use of Crosstube No. 5 include insertion of a horizontal acceleration section ahead of the vertical section, design of a lengthened injector section, and use of a rotary airlock feeder.

HORIZONTAL ACCELERATION SECTION

A 1500-mm (60-in.) horizontal acceleration section could be installed after the first elbow downstream from the injector.

Although this would add an elbow and more run length, it might have improved performance and would not have increased machine width. Pneumatic lines on the machine would need to be relocated.

LENGTHENED INJECTOR SECTION

A larger injector section incorporating standard pipe lengths and bend radii could be used if the injector were mounted parallel to machine travel direction so that machine width did not constrain length. This choice would have meant complete redesign of both the pneumatic system and the belt conveyor feeder.

ROTARY AIRLOCK FEEDER

Use of a rotary airlock feeder would eliminate the injector and allow grain to drop directly into the pipeline. It would also reduce pressure losses and eliminate interference with winnowing air. Possibly an airlock would allow use of a smaller blower. Drawbacks precluding its use include high cost of the airlock and its drive mechanism and probable grain damage if not properly designed.

CONCLUSION

A material throughput rate of 77 kg/min (169 lb/min), exceeding the goal of 75 kg/min (154 lb/min), was obtained with dry corn and Crosstube No. 5, which incorporates three baffles and a blowback chamber. This crosstube was selected as a suitable design in terms of throughput and manufacturing costs and was placed in production. Performance has proven to be adequate.

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