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Design and Development of the Caterpillar 7155 Semi-Automatic Heavy-Duty Truck Transmission

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THE HEAVY-DUTY TRUCK INDUSTRY has experienced rapid expansion in recent years. This expansion has necessitated training many new drivers and mechanics. Reducing the effort, skill, and attention required of the starting and gear change process while retaining positive control improves the beginning, unskilled, and skilled driver's performance. Several innovations in the clutch-transmission portion of the power train have been introduced to the industry. Some of these ideas have gained wide acceptance and others have been discontinued, are used in special applications, or continually reappear but have limited success.

ENGINE OBJECTIVES

The engineering objectives were to find an improved method for converting the output of the prime mover to the demands of the vehicle. These objectives included a target cost between the planetary, multi-clutched, torque converter type and the more conventional unsynchronized, constant mesh type of transmissions. Also desired was an efficiency greater than 95%, possibly even greater than the conventional transmissions. Driver effort and skill requirements were to be reduced while convenience was to be improved. Further objectives were to be able to handle the higher horsepower engines planned and to have improved startability to match the larger, heavier vehicles of the future. The 7155 Transmission achieves these objectives.

DESCRIPTION OF OPERATION

The 7155 Transmission is a 16 forward, two reverse ratio, semi-automatic, quick shifting mechanical drive transmission. Figure 1 shows the major groups within the transmission and Figure 2 shows the cab mounted selector control.

The driver controls the shift initiation and gear ratio selection by moving the selector lever in the truck cab. The shift is made automatically when an air pressure signal is sent from the ratio selector to the transmission control group.

ABSTRACT

The heavy-duty truck industry has seen the need for a change in the concept of transmission design for many years. Several improvements have been made and others attempted, but greater improvement is needed to match the engine's delivery to the vehicle's demand. Driver performance can be improved and fatigue reduced by lowering the effort and skill required to make smooth, consistent starts and ratio changes. This paper discusses a solution to this need in the design and development of a semi-automatic, pneumatically controlled, constant mesh transmission.

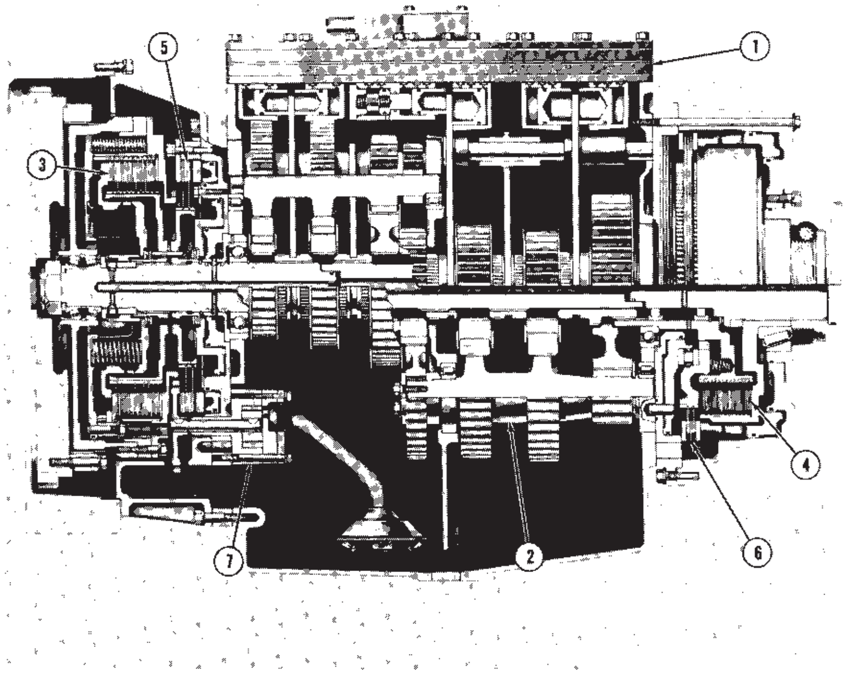

Fig. 1-7155 Transmission groups

1. Transmission control. 2. Gear group.
3. Input clutch. 4. Output clutch.
5. Input brake. 6. Output brake.
7. Oil pump.

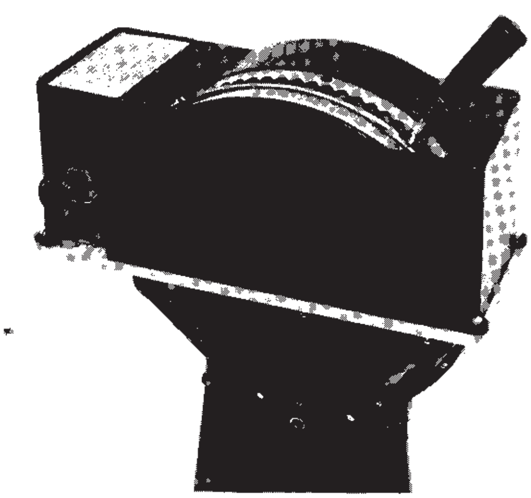

Fig. 2-7155 Ratio selector

The transmission control performs all shifts in the following sequence:

1. The gear group of the transmission is temporarily disconnected from the engine by the input clutch and disconnected from the drive line by the output clutch.
2. The rotation of the gear group is stopped by the input and output brakes.
3. The collars in the gear group are moved to the new gear ratio.
4. The brakes are released and the collars engaged.
5. The gear group is reconnected to the engine by the input clutch and to the drive line of the truck by the output clutch. The shift is now complete.

This method of shifting, referred to as "stop and go", takes place in less than one second.

When starting the truck, the input clutch is automatically engaged by centrifugal force from a torus of oil within the clutch as the engine speed increases.

The oil to fill the torus, to cool the clutches and brakes, and to cool and lubricate the gears and bearings is circulated by the oil pump driven continuously by the flywheel.

DESCRIPTION OF GROUPS

INPUT GROUPS

INPUT CLUTCH - The input clutch (Fig. 3) connects the engine flywheel to the transmission input shaft. This clutch uses ten clutch discs with a fibrous friction material and ten steel clutch plates. The clutch plates and discs are oil cooled.

All the components of the input clutch except the output hub and the discs are connected to and turn with the engine flywheel. The discs and the hub are connected to the transmission input shaft.

At low idle, the start springs hold the start piston against the adapter and washers (29) on the bolts prevent the pressure plate from contacting the clutch plates and discs.

The diverter valve is positioned to allow a small quantity of oil to fill the space between the piston and adapter and to lubricate the disengaged clutch.

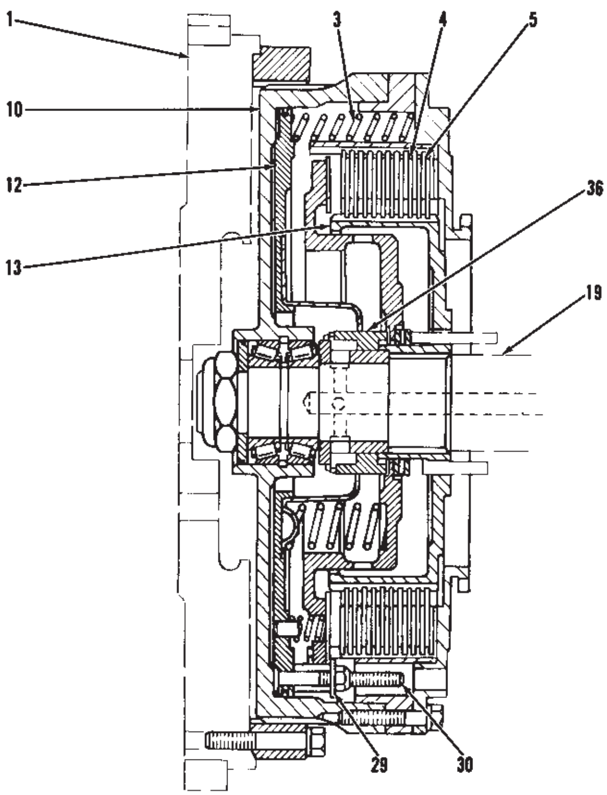

Fig. 3-Input clutch released at low idle

1. Engine flywheel. 3. Start spring.
4. Clutch disc. 5. Clutch plate.
10. Adapter. 12. Start piston.
13. Output hub. 19. Input shaft.
29. Washer. 30. Bolt. 36. Diverter valve.

As the engine speed is increased above approximately 775 rpm (Fig. 4), centrifugal force causes the oil in the space between the piston and the adapter to increase in pressure. This moves the piston to the right and causes the compression of the start springs. The piston moves until it makes contact with the hub at approximately 1000 rpm. The start piston moves the diverter valve to the right, allowing maximum oil flow to cool the clutch.

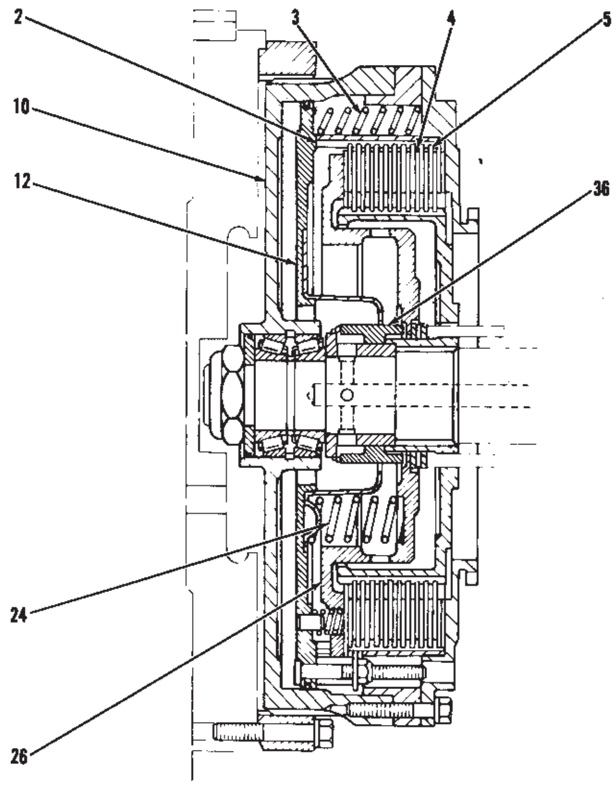

Fig. 4-Input clutch engaged

2. Input hub. 3. Start spring.
4. Clutch disc. 5. Clutch plate.
10. Adapter. 12. Start piston.
24. Load spring. 26. Pressure plate.
36. Diverter valve.

As the piston is moved to the right, the pressure plate is moved toward the clutch plates and discs. After the pressure plate makes contact with the clutch stack, any more movement of the piston compresses the load springs. The compression force holds the clutch plates and discs together.

In this position, the clutch is fully engaged and power from the engine is sent to the input shaft of the transmission.

While making a shift (Fig. 5), the input clutch must be disengaged. Before moving the shift collars in the gear group, the transmission control sends air pressure to a space behind the clutch piston. This moves the piston to the left, pushing the pins toward the pressure plate. Movement of the plate closes the diverter valve. This reduces oil to the clutch during a shift and compresses the load springs, releasing the input clutch.

The guide pins and springs keep the thrust bearings in contact with their races when the clutch piston is released.

Rollover springs hold the rollover plate in contact with the clutch plates and discs during a shift. This causes a small amount

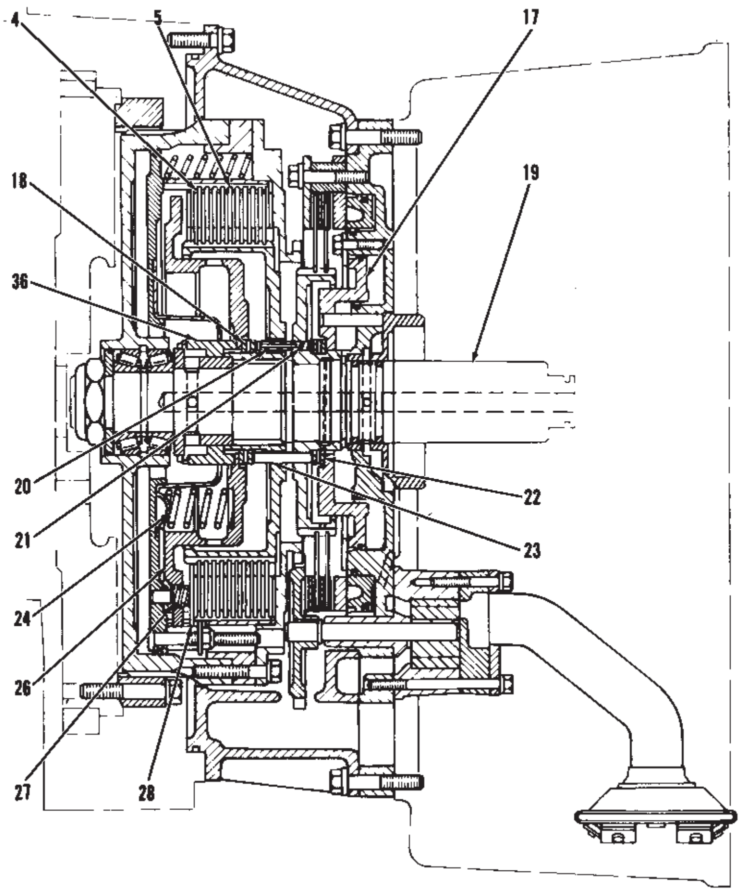

Fig. 5-Input clutch released during a shift

4. Clutch disc. 5. Clutch plate.
17. Clutch piston. 18. Thrust bearing.
19. Input shaft. 20. Guide pin. 21. Spring.
22. Thrust bearing. 23. Pin. 24. Load spring.
26. Pressure plate. 27. Rollover spring.
28. Rollover plate. 36. Diverter valve.

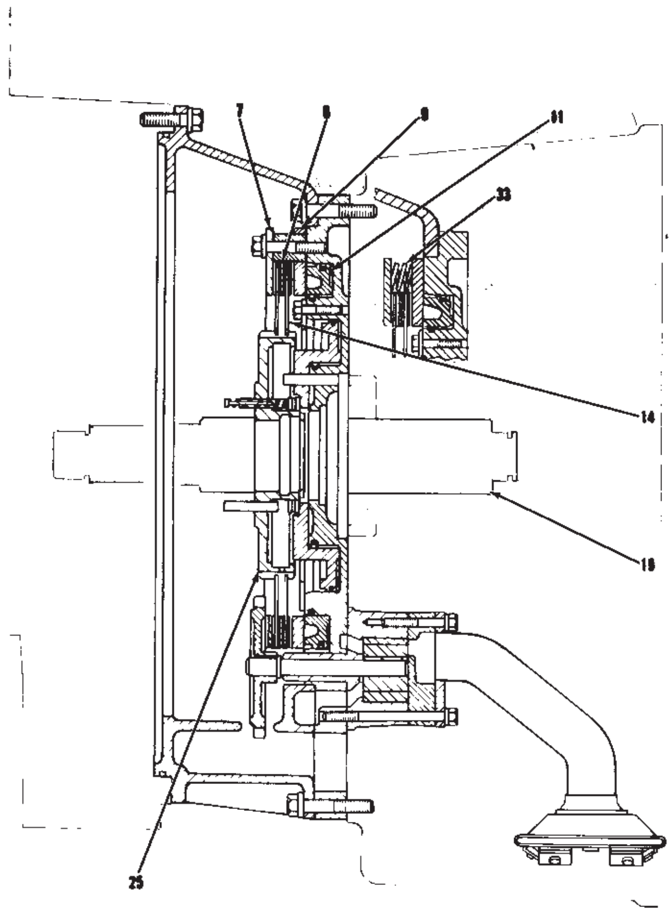

Fig. 6-Input brake applied

7. Reaction plate. 8. Brake plate.
9. Pressure plate. 11. Brake piston.
14. Brake disc. 19. Input shaft.
25. Brake hub. 33. Retraction spring.

of torque to be delivered to the transmission input shaft to assist the collar engagements during a shift, by rolling the gear group slowly after the input brake has been released.

After the gear couplings are engaged, the transmission control exhausts the air pressure from behind the clutch piston. The force of the load springs causes the pressure plate to move to the right, engaging the clutch.

INPUT BRAKE - The input brake (Fig. 6) is connected to the input shaft of the transmission. This brake uses two brake discs with a fibrous friction material and one steel plate. The discs and plate are cooled by a continuous flow of oil.

The brake hub and discs turn with the input shaft while the plates are held stationary. The retraction springs are trapped between the reaction plate and the pressure plate holding the brake piston to the right. In this position, the discs and the input shaft are free to rotate.

While making a shift, the input brake must be applied. Before moving the collars, the transmission control sends air pressure to a space behind the piston. This air pressure moves that piston to the left until the discs and plates are pushed together, stopping the gear group.

After the gear couplings are moved, the transmission control exhausts the air pressure from behind the piston. The force of the springs causes the discs and plates to move apart, and the input shaft is free to turn again.

LUBRICATION - An oil pump (Fig. 7) (32), driven by a gear on plate (6), turns with the engine flywheel. The output of the oil pump is 29.0 U.S. gpm (109.8 lit/min) at 2000 rpm engine speed.

At approximately 1200 rpm engine speed or 12 psi (82.7 kPa) oil pressure, a priority

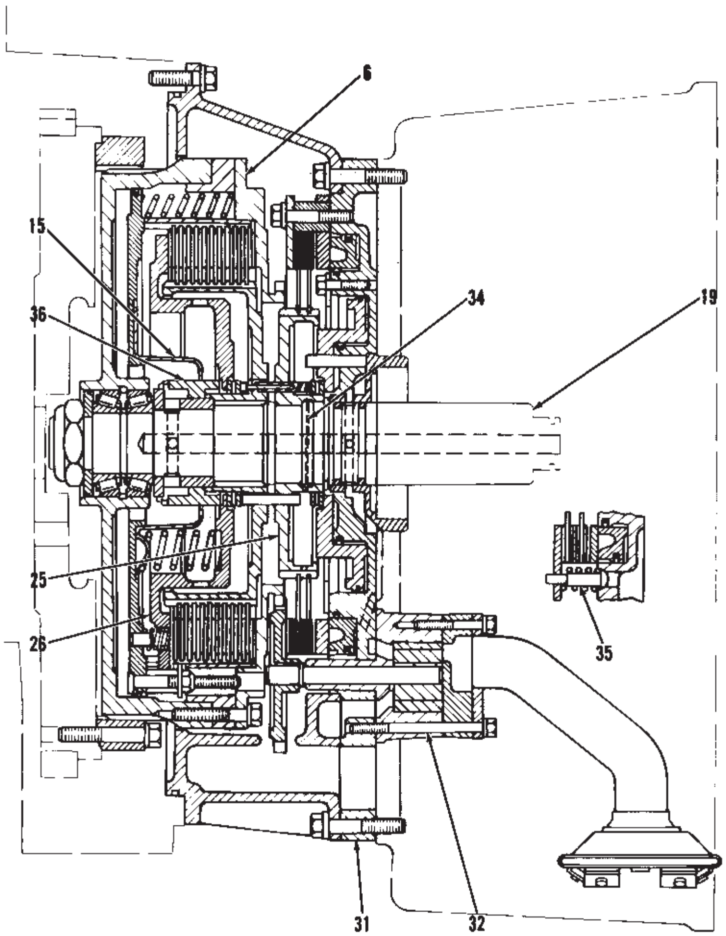

Fig. 7-Lubrication of input clutch and brake

6. Plate. 15. Deflector. 19. Input shaft.
25. Brake hub. 26. Pressure plate.
31. Mounting plate. 32. Oil pump. 34. Hole.
35. Relief valve. 36. Diverter valve.

valve opens to increase flow to the gear group.

The normal oil pressure in the system is approximately 25 psi (172 kPa). A relief valve will open at 35 to 40 psi (241 to 276 kPa) to prevent cold oil from causing excessive oil pressure.

The oil for lubricating and cooling the input clutch and brake is sent from the pump through a passage in the mounting plate to a hole in the center of the input shaft.

The oil for the input clutch goes through or by the diverter valve into a reservoir made by the deflector. When the reservoir is full, oil flows to holes in the pressure plate to cool the clutch.

The oil for the input brake goes through two small holes in the input shaft and out through holes in the brake hub to cool the brake.

GEAR GROUP

DESIGN - The gear group has two arrangements. The direct drive arrangement gives a 17.23 to 1 reduction in 1st gear with a one to one ratio in 16th gear, and the overdrive arrangement gives a 14.48 to 1 reduction in 1st gear with a .825 to 1 ratio in 16th gear. Both arrangements look and operate the same and have approximately 21% step ratios. The only differences are the number of teeth on some of the gears and the sequence of shift fork movement for a given gear selection.

The gear group (Fig. 8) is a three countershaft design. The front section of the transmission has a set of three identical countershafts and the rear section of the transmission has a set of three identical countershafts with the same distance between each countershaft and the main shaft.

The three main shaft gears in each section of the transmission have radial support by their location between the countershafts. These gears (Fig. 9) get axial support from (typical) side plates (21 and 23) that make contact with the sides of the countershaft gears. The six countershafts are supported in the transmission case by roller bearings.

A set of three main shaft gears (19, 22, and 25) is engaged with the front set of countershafts. A set of three main shaft gears (11, 13, and 15) is engaged with the rear set of countershafts. A main shaft gear (27) is engaged with the reverse idler gear, which is cantilevered from the rear countershaft.

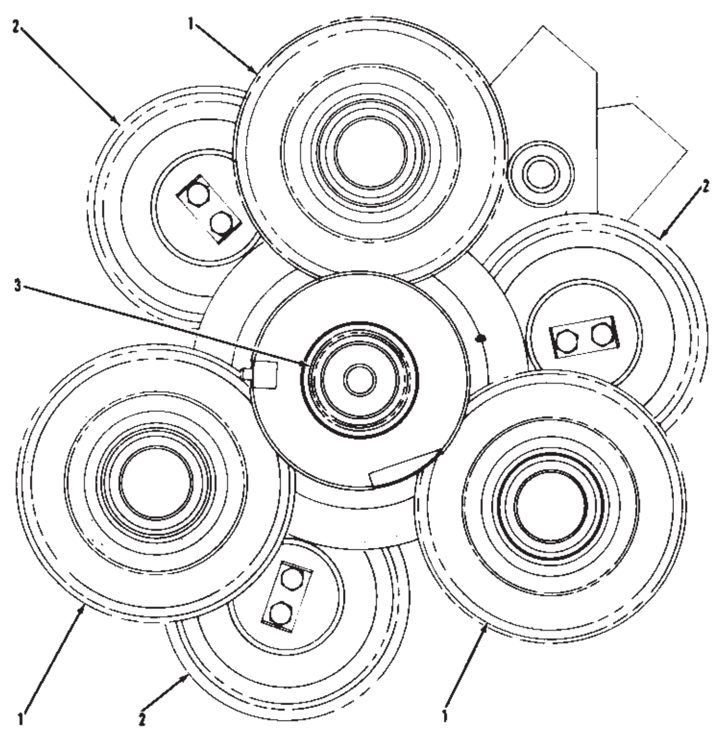

Fig. 8-Gear group (front view)

1. Front countershaft. 2. Rear countershaft.
3. Main shaft.

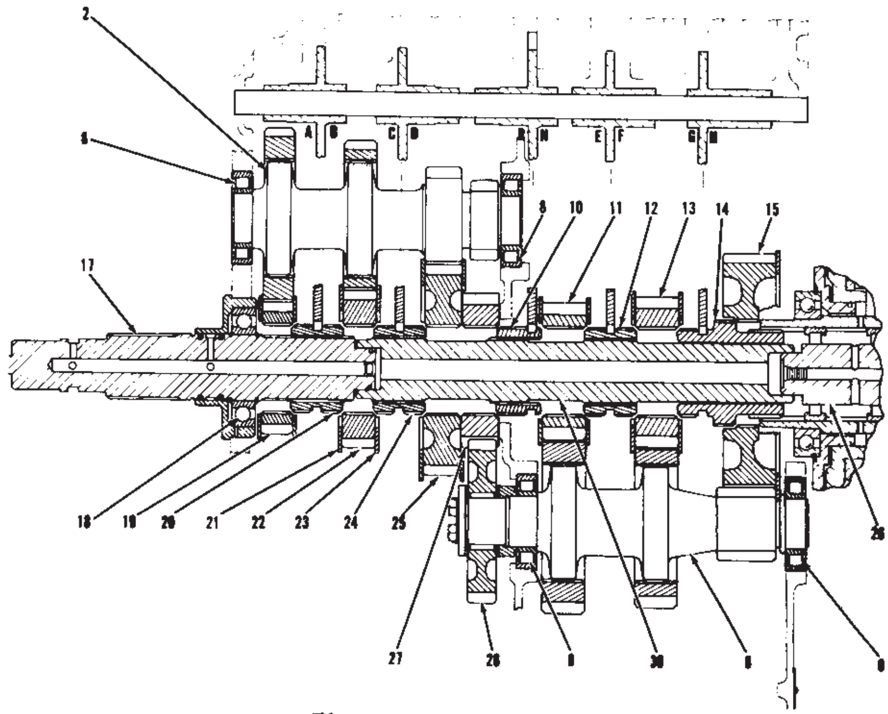

Fig. 9-Gear group

2. Front countershaft..6. Rear countershaft.
8. Roller bearing. 10. R-N collar.
11. Main shaft gear. 12. E-F collar.
13. Main shaft gear. 14. G-H collar.
15. Main shaft gear. 17. Input shaft.
19. Main shaft gear. 20. A-B collar.
21. Side plate. 22. Main shaft gear.
23. Side plate. 24. C-D collar
25. Main shaft gear. 26. Output shaft.
27. Main shaft gear. 28. Reverse idler gear.
30. Intermediate shaft. A-B. Shift fork.
C-D. Shift fork. R-N. Shift fork.
E-F. Shift fork. G-H. Shift fork.

OPERATION - Five shift forks (Fig. 9) are moved by air cylinders in the transmission control. These shift forks move sliding collars which are connected to the main shafts with splines. By moving a sliding collar into engagement with a main shaft gear, power is directed either to the countershafts from the main shaft or to the main shaft from the countershafts.

All shift forks can move to either the right or the left. Shift fork (C-D) can also be held in the center position. Figures 10 and 11 show the position of each of the five shift forks for each gear ratio available.

Power comes through the input clutch to the input shaft. Shift fork (A-B) slides collar (20) to engage with either gear (19) or gear (22) and power is sent to and divided between the three front countershafts. Shift fork (C-D) slides collar (24) to engage with either gear (22) or gear (25) and power is sent from the countershafts to the intermediate shaft (30). The intermediate shaft then turns in the same direction as the input

DIRECT DRIVE ARRANGEMENT						
REDUCTION	RATIO	SHIFT FORK POSITION				
		A-B	C-D	R-N	E-F	G-H
17.23	1	A	D	N	E	H
14.25	2	A	D	N	F	H
11.74	3	B	D	N	E	H
9.72	4	B	D	N	F	H
8.04	5	A	C	N	E	H
6.65	6	A	C	N	F	H
5.48	7	B	C	N	E	H
4.53	8	B	C	N	F	H
3.80	9	A	D	N	E	G
3.14	10	A	D	N	F	G
2.59	11	B	D	N	E	G
2.14	12	B	D	N	F	G
1.77	13	A	C	N	E	G
1.47	14	A	C	N	F	G
1.21	15	B	C	N	E	G
1.00	16	B	C	N	F	G
	N	A	CENTER	N	E	H
17.23	R1	A	CENTER	R	E	H
9.72	R2	B	CENTER	R	F	H

Fig. 10-Position of shift forks for available gear ratios in direct drive arrangement

shaft. When sliding collar (20) is engaged with gear (22) and collar (24) also is engaged with gear (22), power goes straight through the front section of the transmission to the intermediate shaft.

The rear section of the gear group is similarly arranged and will provide four ratios. The rear section output is sent through the output clutch to the output shaft.

In reverse, shift fork (C-D) is held in its center position and shift fork (R-N) is moved to the left to engage collar (10) with gear (27). That gear is in engagement with the three reverse idler gears which are in engagement with the front countershafts which are turning in the opposite direction to the input shaft. Power is sent from the front countershaft through the reverse idler gears that are turning in the same direction as the input shaft. From the reverse idler gears, power is sent through main shaft gears (27) and through the collar (10) to the intermediate shaft. The intermediate shaft is now turning in the opposite direction as the input shaft.

The gear connections for shift forks (E-F) and (G-H) are the same as in the earlier explanation except the direction of rotation is reversed.

OVERDRIVE ARRANGEMENT							
REDUCTION	RATIO	SHIFT FORK POSITION					
		A-B	C-D	R-N	E-F	G-H	
14.77	1	A	D	N	F	H	
12.21	2	A	D	N	E	H	
10.07	3	B	D	N	F	H	
8.33	4	B	D	N	E	H	
6.89	5	A	C	N	F	H	
5.70	6	A	C	N	E	H	
4.70	7	B	C	N	F	H	
3.89	8	B	C	N	E	H	
3.14	9	A	D	N	F	G	
2.60	10	A	D	N	E	G	
2.14	11	B	D	N	F	G	
1.77	12	B	D	N	E	G	
1.47	13	A	C	N	F	G	
1.21	14	A	C	N	E	G	
1.00	15	B	C	N	F	G	
.83	16	B	C	N	E	G	
	N	A	CENTER	N	F	H	
14.77	R1	A	CENTER	R	F	H	
8.33	R2	B	CENTER	R	E	H	

Fig. 11-Position of shift forks for available gear ratios in overdrive arrangement

LUBRICATION (Fig. 12) - The pump sends oil through passages in the front transmission case to two tubes that are installed parallel to the main shaft of the transmission. Each tube has eight small radial holes drilled in it. When pressure oil is in the tube, it will flow through these holes and lubricate the gears and bearings of the gear group.

The priority valve in oil tube (33) reduces flow to the gear group and supplies extra oil to the input clutch during starting

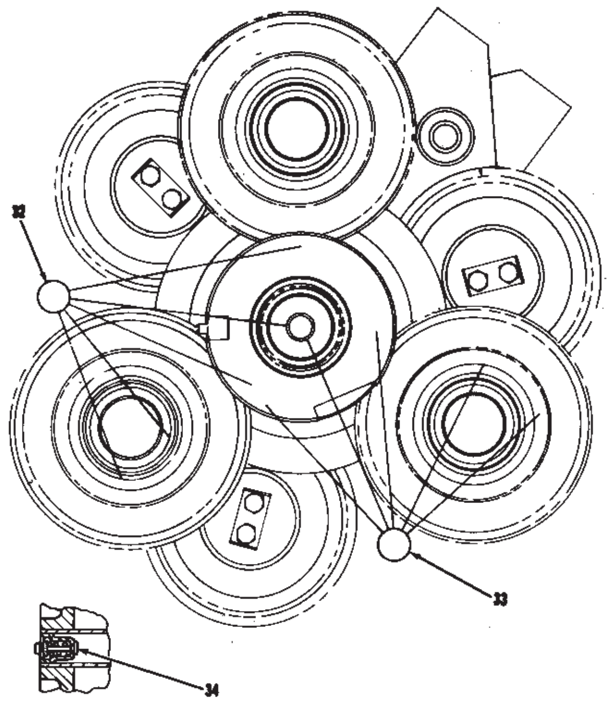

Fig. 12-Gear group lubrication

32. Oil tube. 33. Oil tube.
34. Priority valve.

at low engine speeds. After the priority valve has opened, oil pressure is in both tubes.

OUTPUT GROUPS

OUTPUT CLUTCH GROUP - The output clutch (Fig. 13) connects the gear group to the output shaft. This clutch uses 13 discs with a fibrous friction material and 12 or more (for the adjustment of clutch thickness) steel plates. The clutch discs and plates are cooled by a continuous flow of oil.

The input shaft, input hub, clutch discs, and pressure plate are connected to and turn with the gear group. The clutch plates and output hub are connected to the output shaft.

The clutch is engaged by air pressure (sent from the transmission control) working between the mounting plate and the clutch piston. As the clutch piston moves to the right, it moves the rotating pressure plate through a thrust bearing. This plate moves to the right until the plates and discs of the clutch are held together. Now the output hub is connected to the input hub and power can go from the gear group to the output shaft of the transmission.

When making a shift, the output clutch must be released. Before moving the collars, the transmission control removes the air

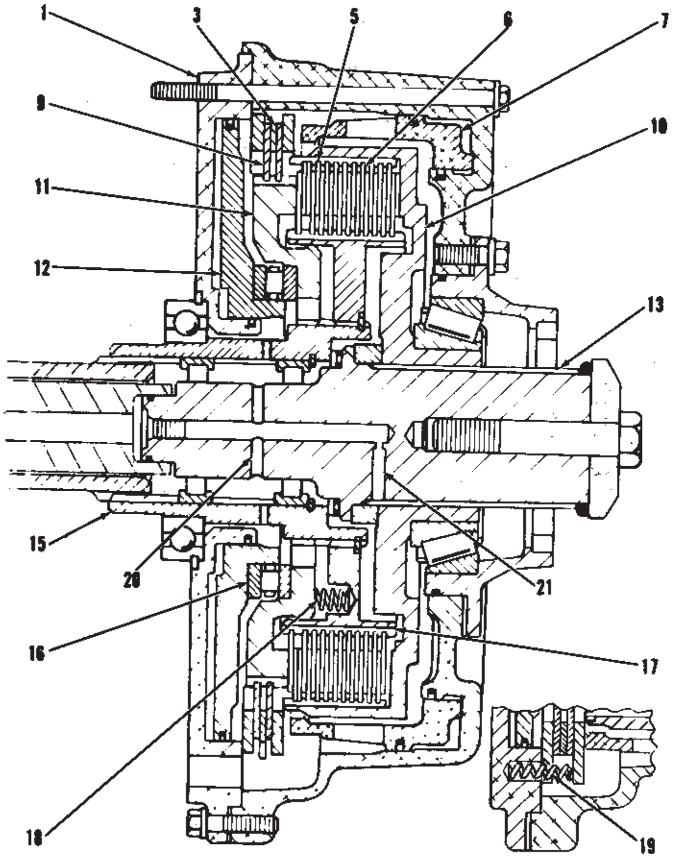

Fig. 13-Output clutch and brake

1. Mounting plate. 3. Brake plate.
5. Clutch plate. 6. Clutch disc.
7. Brake piston. 9. Brake disc.
10. Output hub. 11. Pressure plate.
12. Clutch piston. 13. Output shaft.
15. Input shaft. 16. Thrust bearing.
17. Input hub. 18. Clutch release spring.
19. Retraction spring. 20. Holes.
21. Hole.

pressure from the clutch piston. With no pressure on the piston, the clutch release springs move the pressure plate to the left, away from the clutch plates and discs, and the clutch is released.

OUTPUT BRAKE - The output brake works in combination with the input brake to stop the rotation of the gear group. The output brake uses two brake discs with a fibrous friction material and one steel plate. The discs and plate are oil cooled.

While making a shift, the output brake must be applied. Before moving the collars, the transmission control sends air pressure to a space behind the piston. This pressure moves the piston to the left until the discs and plates are pushed together, stopping the gear group. After the collars are moved, the transmission control removes the pressure from behind the piston. The force of the retraction springs causes the discs and plates to separate as the piston moves back to its original position. Now the gear group is free to rotate again.

LUBRICATION - Oil for lubrication and cooling of the output clutch and brake is carried through the center of the transmission shaft to the center of the output shaft. Two holes (20) in the output shaft provide oil for the lubrication of the ball, roller, and thrust bearing as well as to cool the output clutch and brake. The additional hole in the output shaft delivers oil for the lubrication of the rear bearing.

CONTROL GROUPS

COMPONENTS - The complete transmission (clutches, brakes, and gear section) is controlled by air pressure from the normal system of the truck. The air is controlled by two position, three way valves and single and double check valves. The valves are connected to passages, orifices, air cylinders, and closed volumes which provide the controls for the transmission.

Two basic types of three way valves are used, pilot operated and mechanically operated. The pilot operated type has two different configurations ... normally closed (Fig. 14) and normally open (Fig. 15). These figures indicate the flow paths for both types of valves with and without pressure applied to the pilot passage. When the pilot pressure is not present, the differential areas of the seat and piston hold the valve closed.

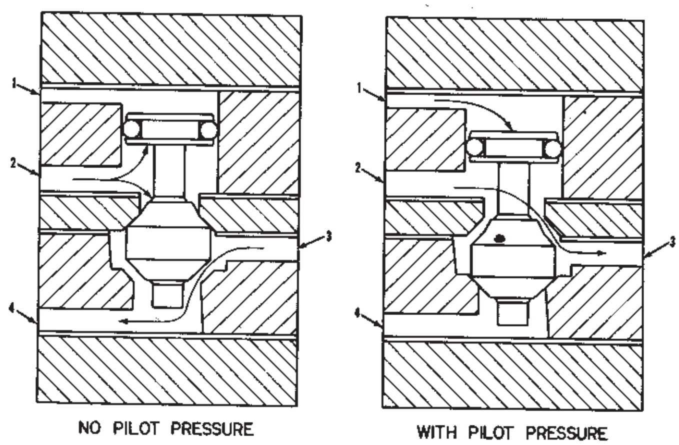

Fig. 14-Normally closed valve

1. Pilot passage. 2. Supply passage.
3. Delivery passage. 4. Supply passage.

The mechanically operated valve (Fig. 16) is normally closed. The figure indicates the flow paths in the operated and unoperated positions. The spring helps the valve follow the cam during operation.

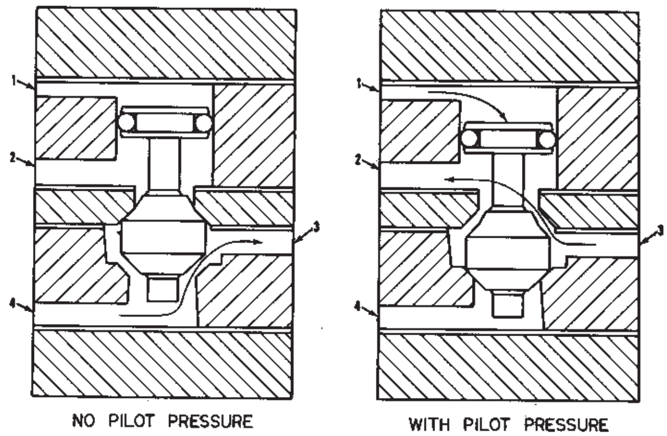

Fig. 15-Normally open valve

1. Pilot passage. 2. Exhaust passage.
3. Delivery passage. 4. Supply passage.

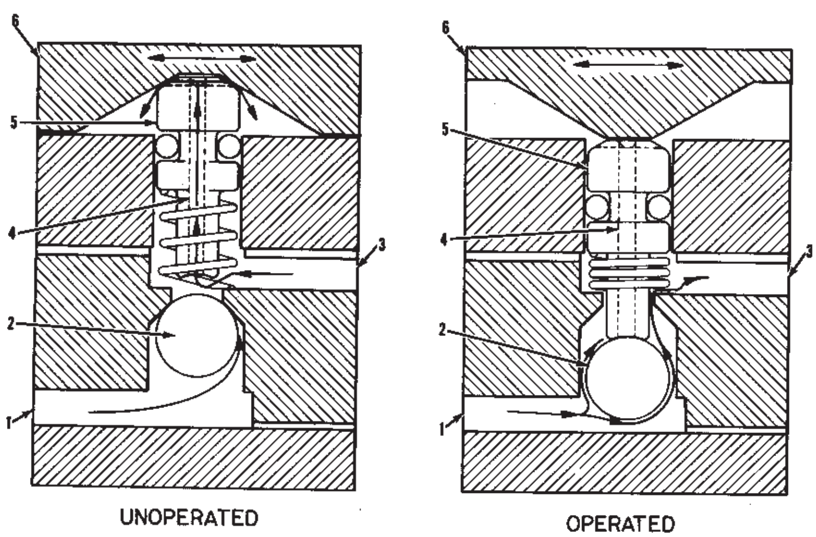

Fig. 16-Mechanically operated valve

1. Supply passage. 2. Ball.
3. Delivery passage. 4. Exhaust passage.
5. Stem. 6. Cam plate.

Double check valves (Fig. 17) and single check valves (Fig. 18) are used. The double check valve directs flow to the delivery passage from either supply passage while the single check valve directs flow from the supply passage and blocks flow from the delivery passage.

AIR SYSTEM FOR SHIFT FORKS - Two air cylinders are used to move each shift fork (Fig. 19). Piston (19) within cylinder (16) moves shift fork (20) toward the rear, and piston (21) within cylinder (17) moves the fork toward the front. An explanation of the air system for shift forks (A-B), (E-F), and (G-H) is given below. The air system for shift forks (C-D) and (R-N) is similar to that for the other forks with some added controls to provide centering for (C-D) as well as forward-reverse inhibiting.

Each air cylinder has its own supply valve. One valve (7) is normally open while the other valve (10) is normally closed. Both supply valves are pilot operated by a mechanically operated valve (4) in the ratio selector. When the mechanically operated valve is closed, no pilot air pressure is sent to the supply valves. Air pressure in the supply line goes through the normally open valve, to the piston. This pressure moves the piston and the shift fork to the

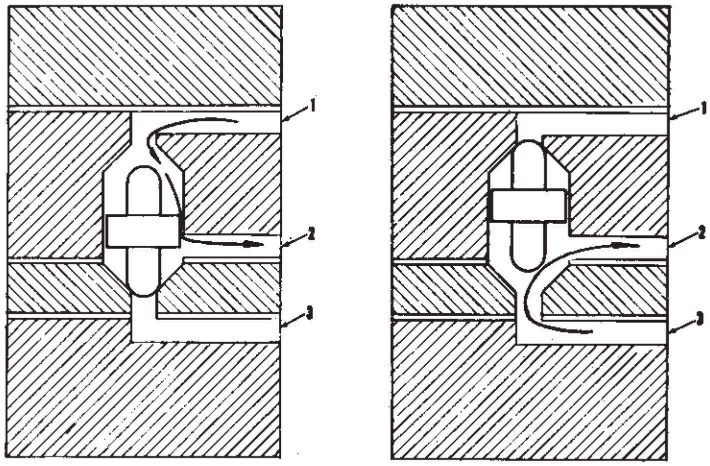

Fig. 17-Double check valve

1. Supply passage. 2. Delivery passage.
3. Supply passage.

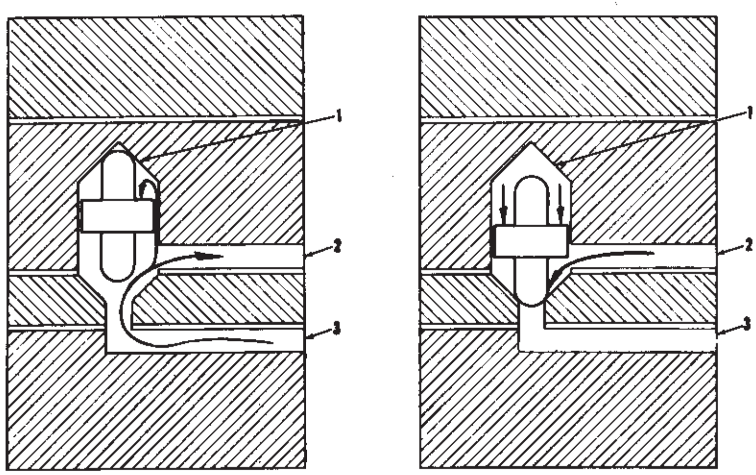

Fig. 18-Single check valve

1. Area. 2. Delivery passage.
3. Supply passage.

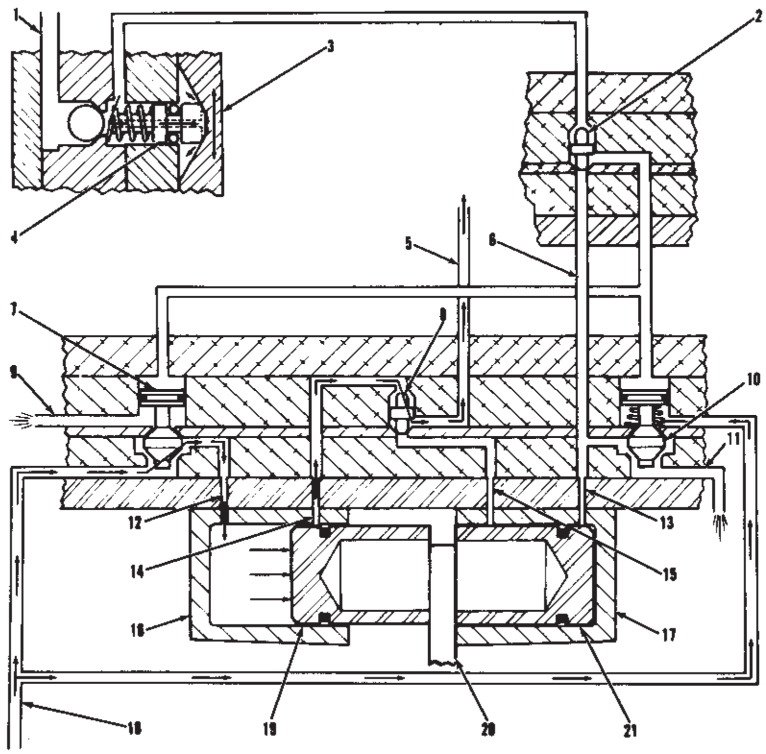

Fig. 19-Air system for shift forks (A-B), (E-F), and (G-H) with mechanically operated valve closed

1. Pilot supply line. 2. Double check valve.
3. Cam plate. 4. Mechanically operated valve.
5. Sensing circuit. 6. Line.
7. Normally open valve. 8. Double check valve.
9. Exhaust. 10. Normally closed valve.
11. Exhaust. 12. Hole. 13. Hole.
14. Sensing hole. 15. Sensing hole.
16. Air cylinder. 17. Air cylinder.
18. Supply line. 19. Piston.
20. Shift fork. 21. Piston.

right (toward the rear of the transmission). The other air cylinder is connected to exhaust through the normally closed valve. After the piston has moved completely to the right, it opens the sensing hole which allows air to flow around the double check valve to the sensing circuit. The air pressure from the sensing hole indicates that the shift fork has moved completely and the sliding collar in the gear group has engaged correctly.

When the mechanically operated valve is opened by the cam plate, pilot pressure is sent around the double check valve (2) to the supply valves. Operation of the supply valves moves the pistons and shift fork to the left (toward the front of the transmission). The air from the normally closed valve moves the check valve up to prevent air from going back to the mechanically operated valve and holds the supply valves in their present positions. The supply air to the mechanically operated valve can now be removed.

The air to the supply valves is exhausted during the start of each shift cycle, allowing both valves to return to their relaxed position for the next command from the ratio selector, illustrated by valve (4). This arrangement allows one air passage to control two positions of the shift fork and collar.

SENSING CIRCUIT - The sensing circuit receives information from all actuator air cylinders. Signals are only allowed to be sent when the associated fork and collar have moved far enough to have made a positive engagement within the gear group. Double check valves and pilot operated valves are used in sufficient quantity to know when the five coupling collars are in their correct positions. The output of the sensing circuit is used by the transmission control to release the brakes and engage the clutches.

PRESSURE REGULATOR - The output clutch

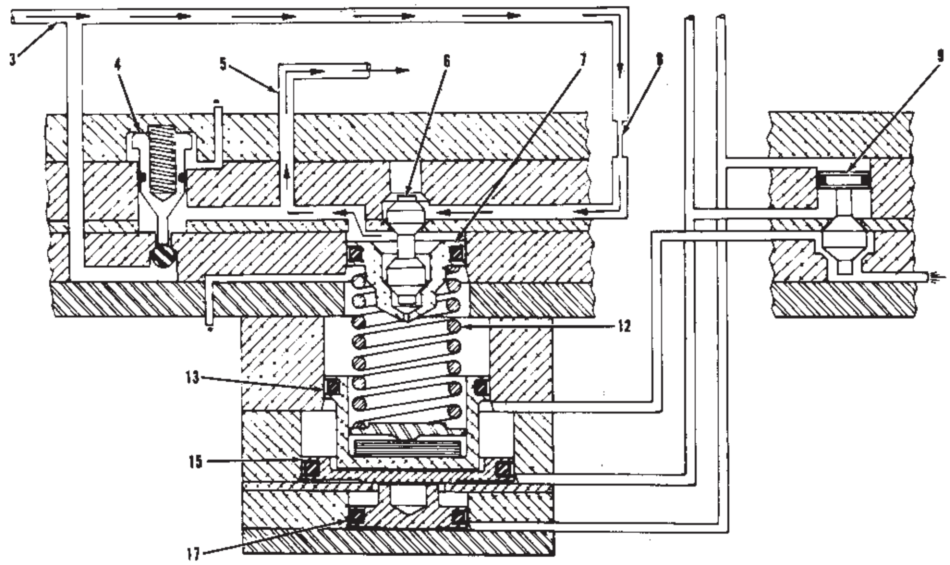

Fig. 20-Pressure regulator

3. Transmission supply line.
4. Quick fill valve.
5. Line to output clutch.
6. Regulator valve. 7. Regulator piston.
8. Orifice. 9. Valve. 12. Spring.
13. Load piston. 15. Load piston.
17. Load piston.

is engaged by air pressure controlled to higher levels for higher torques by a pressure regulator (Fig. 20). The pressure regulator reduces the load on the output clutch components, increasing their life. Air pressure flows from the transmission supply line, through the orifice, to the regulator valve. When the air pressure to the output clutch is less than the pressure setting, the regulator spring force moves the regulator piston up and opens the valve. If the air pressure to the output clutch is too high, the regulator piston and valve move down to stop supply air from flowing through the regulator, and if necessary the piston moves further than the valve, relieving the over-pressure.

The pressure regulator receives signals from the actuator air system to adjust the load on the regulator spring by moving the load pistons. Valve (9) combines two of these signals for the maximum air pressure.

QUICK FILL VALVE - The quick fill valve allows air pressure from the transmission supply line to flow around the ball directly to the output clutch piston. This lets the output clutch piston fill more rapidly than if the flow came through the orifice and regulator. When the pressure in the output clutch piston becomes approximately 6 psi (41.4 kPa), the force on the quick fill valve overcomes the spring force and the valve closes. With the valve closed, air flow through the orifice and pressure regulator modulates the output clutch engagement.

SHIFT CYCLE CIRCUIT - The shift cycle circuit is composed of pilot operated valves (Fig. 14 and 15), double check valves (Fig. 17), single check valves (Fig. 18), orifices, and volumes. The valves control the direction of flow of air and the orifices and volumes determine time delays for sequencing the functions of the control. Exhausting the shift signal in the ratio selector by moving the shift lever to the right (Fig. 2) initiates the sequence of the shift cycle. The first operation is to fill the input clutch piston (Fig. 5), exhaust the output clutch piston (Fig. 13), and exhaust the actuator supply circuit (Fig. 19, line 18). After sufficient delay for filling and exhausting the clutch pistons, the input (Fig. 6) and output (Fig. 13) brake pistons are pressurized.

The cam plate (Fig. 19, item 3) determines the mechanically operated valves that will be actuated for the ratio selected and applies air pressure to the pilot pistons of the appropriate actuator valves.

The second delay determines when the input brake piston (Fig. 6) will be exhausted and the actuator supply reapplied (Fig. 19, line 18). The actuator valves (Fig. 19) direct air to the correct air cylinders, moving the shift fork and collars in their correct direction. With the input brake released, the input clutch applies low level torque to the gear group (Fig. 9), rotating the collars and main shaft gears until the teeth engage (when necessary). When all collars have been engaged, determined by the actuator pistons having uncovered the sensing signal holes of all air cylinders, the output brake is released, and the input and output clutches are engaged.

On the rare occasions when all the collars do not engage in a short period of time, a third timer releases the air behind the output brake piston allowing the whole gear group to rotate. This final rotation may finish the collar engagement, but occasionally the control must be recycled. This third timer also communicates with the ratio selector preparing it for the next shift.

DEVELOPMENT

COMPONENT TESTING - Laboratory evaluations of potential components were begun long before a complete transmission was designed. Most of that work centered around development of the pneumatic controls, gear couplings, and means to connect and disconnect the output. From that work, design parameters were established and a complete transmission was built for lab and vehicle evaluations. The present design then evolved as experience was gained. After performance and durability tests in the lab and in proprietary trucks had demonstrated the reliability of the design, evaluations of units in customer-owned trucks were begun. Concurrently, changes and improvements which were suggested by our field experience were evaluated in the lab.

There have been many laboratory performance and durability tests of components. A few of the major tests which supplement the explanation of how the unit functions will be discussed.

START TESTS - Much of the shift performance and durability testing was performed on the test setup shown in Figure 21. That setup included a 270 HP engine, a 7155 Transmission, and an eddy current absorption dynamometer. One test was performed to evaluate the durability of the centrifugally engaged clutch on a start. A 72,000 Lb. (33,000 Kg) gvw truck was instrumented and data was recorded during starts from a standstill on the level in various gears. The results indicated that the input clutch absorbed 340 BTU (359 kJ) of energy during a start in 8th gear. That was a severe test for the input clutch because 4th gear is recommended for starting a 72,000 Lb. (33,000 Kg) vehicle on the level. In the lab, 12th gear was used to provide effective inertia at the input equivalent to that of a loaded truck in 8th gear and the dyno load was adjusted to simulate the rolling resis-

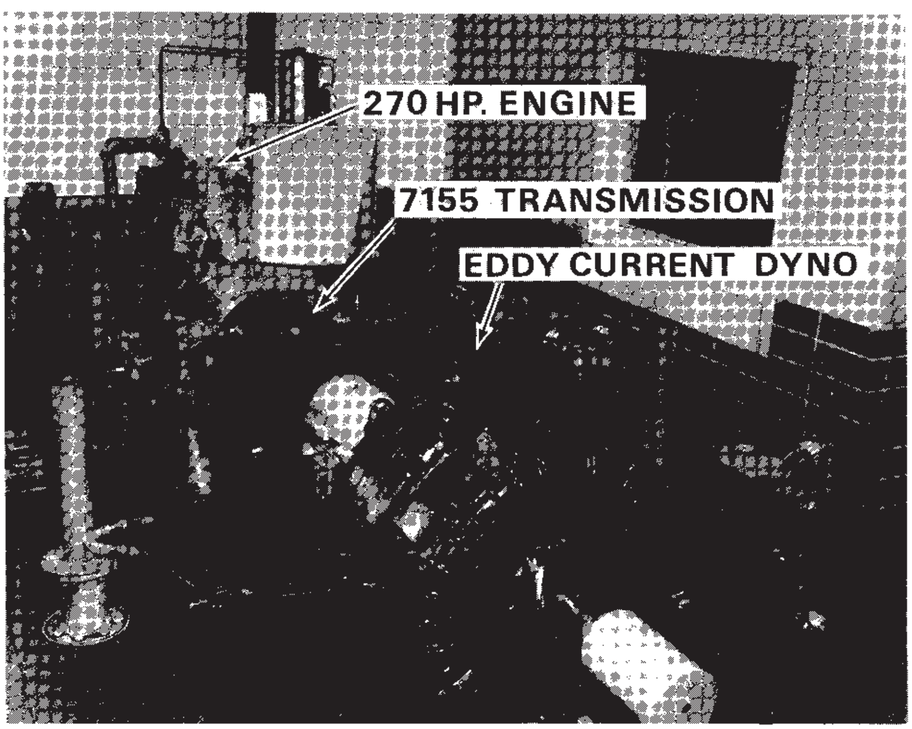

Fig. 21-Performance and durability test setup

tance. After 5000 starts, the input clutch was in excellent condition with no measurable wear.

A typical oscillogram of the input clutch engagement when the governor control was advanced rapidly to the full-open position is shown in Figure 22. Note that the engine speed of the oil in the torus lagged the flywheel speed during the rapid engine acceleration. In a truck, the overshoot can be avoided and the rate of torque buildup can be controlled by how rapidly the driver accelerates the engine.

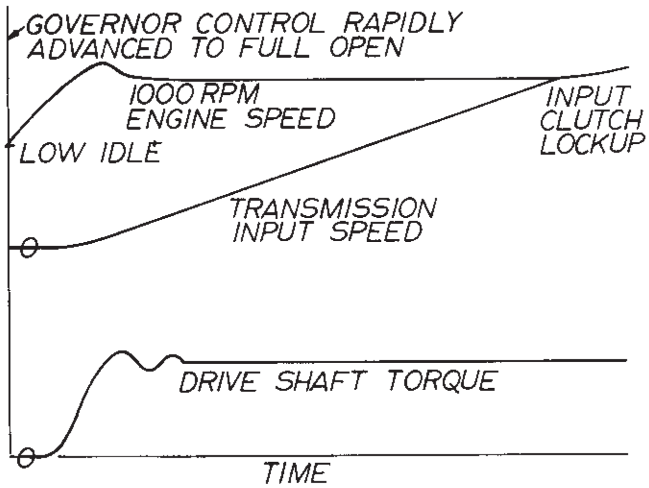

Fig. 22-Centrifugal clutch engagement

SHIFT CYCLE - Another test was a 500,000 shift run on an 8-9-8 cycle. That cycle was selected because all collars (except reverse) were shifted. A typical oscillogram of an 8-9 shift is shown in Figure 23. As discussed earlier, all of the shift cycles are the same except for the selection of the proper collar or collars to be engaged to provide the selected ratio. A shift will be discussed with reference to Figure 23. When the shift lever is moved out of a notch, rotated, and allowed to move back into another notch, a shift cycle is initiated. The input clutch pressure rises and the rear clutch pressure exhausts to release those clutches. After a timed interval, both the input and output brakes are applied to bring the gears to a stop. A second timer (controlled pressure rise rate within an appropriate volume being supplied through a properly sized orifice) then causes actuator supply pressure to direct air to the actuators required to provide the selected ratio. In the example (8-9 shift), all four collars are shifted. All other shifts are either one, two, or three collar shifts. The rise of actuator supply pressure then turns off the input brake. The release of the input brake allows

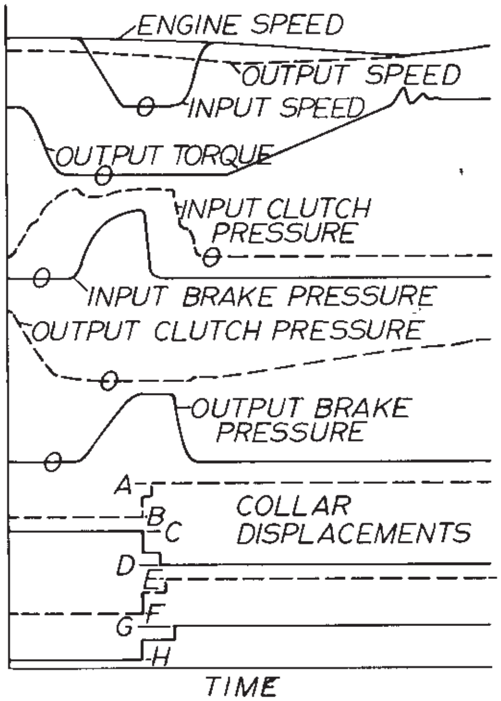

Fig. 23-Oscillogram of 8-9 shift cycle

the built-in drag of the input clutch (referred to as rollover) to rotate any butted couplings into engagement. The output brake remains applied to prevent rotation of the output side of those couplings. In the example, all four collars were shown to have butted. The occurrence of butts is random. Sometimes the collar teeth line up with the internal spaces of the mainshaft gear splines and the couplings engage when they move across. When all of the selected collars have engaged, an air pressure signals the cycle to progress. The output brake pressure then exhausts to release that brake, the input clutch pressure exhausts to reengage that clutch and reconnect the gears to the engine, and the output clutch pressure begins to rise at a controlled rate to reconnect the gears to the drive shaft with a gradual torque buildup for a smooth shift feel. The shift times vary slightly but are always less than 1.0 sec., depending upon how many collars are shifted as well as how many of them butt.

DRIVE TRAIN SIMULATOR - The test setup shown in Figures 24 and 25 can be thought of as an indoor proving ground where precise tests of components or systems can be conducted under closely controlled repetitive conditions. The 1693 engine without the fan and accessories is equivalent to a 450 HP engine in a truck. The 7155 Transmission is mounted to the engine flywheel housing and a truck drive shaft connects the output to the simulator. The drive system mechanically simulates the mass-elastic system of a loaded truck and its motion resistance as reflected

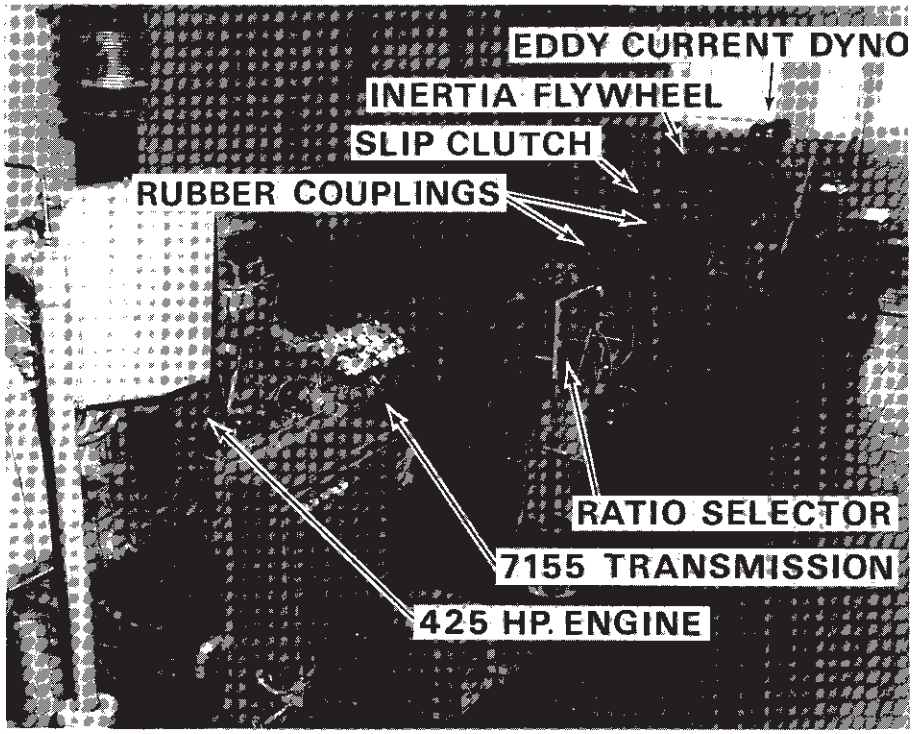

Fig. 24-Drive train simulator test setup

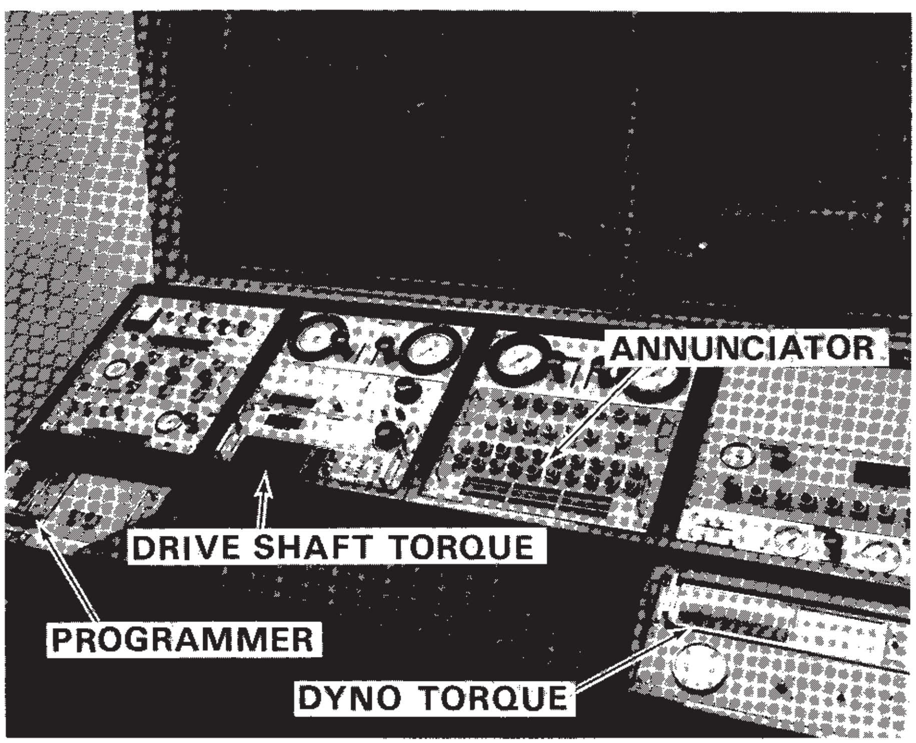

Fig. 25-Control console for drive train simulator

to the transmission output shaft. Physically, the transmission drives into a series of specially designed rubber couplings, a slip clutch, an inertia flywheel, and finally an absorption dynamometer. The rubber couplings simulate the axle shaft and tire stiffness as well as damping inherent in wheeled vehicles. The slip clutch simulates the traction limit of the drive wheels. On a vehicle, tire slippage effectively limits torque peaks, particularly during shifts. The inertia flywheel simulates the mass of a loaded truck. The eddy-current absorption dynamometer equipped with a special field-forcing control is programmed to simulate motion resistance ... rolling, grade, and wind.

The setup includes a ratio selector which is positioned by cylinders to simulate driver's motions. Major features of the control console (Fig. 25) include the programmer, indicators for speeds, pressures and temperatures, torque indicators for both drive shaft and dynamometer torques, and the safety shutdown annunciator. The programmer has one analog channel which controls dynamometer load as well as space for 25 digital channels to control such functions as engine speed settings and transmission gear selections. Automatic safety shut-down circuits protect the facility and the first-out annunciator indicates which condition shut the test down.

SIMULATOR TEST CYCLE - The test cycle was developed from observations and measurements recorded during operation of a loaded truck. Every attempt was made to provide realistic loads ... only time was compressed. The cycle is now programmed to operate the transmission on a 1.6 mile (2.57 km) course in 4 minutes with grades varying from 0.4 to 13.7%. The transmission shifts through 10 of the 16 gears, skipping 1, 2, 3, 5, 7, and 9 much as an operator might normally do. The cycle begins with the engine at low idle, the transmission in neutral, and the dynamometer load equivalent to truck rolling resistance. The transmission is then shifted to 4th and the engine is accelerated to engage the centrifugally operated clutch. During the acceleration, load is rapidly applied by the dyno and then slowly decreased to allow the engine to accelerate to the upshift speed. After the 4-6 shift, load continues to drop gradually to allow the engine to reaccelerate. This sequence continues until the transmission gets to 16th when the load begins to increase gradually to lug the engine to the downshift speed. Single step downshifts occur until the unit gets to 12th where again the load begins to decrease and permit upshifts back to 16th. The downshift sequence is then repeated and continues until the transmission is back to neutral. Essentially, the truck is going up grades, coming to a stop sign, and then going up the grades again. This is a severe cycle for the transmission. We consider that 50,000 shifts are equivalent to over 100,000 miles (160,900 km) of operation in a line haul truck on many transmission components.

Two production units have completed 300,000 shifts - 600,000 equivalent miles (965,400 km) - each on this cycle with no indications of pending problems.

FIELD TESTING - Anyone who is familiar with the introduction of new products knows

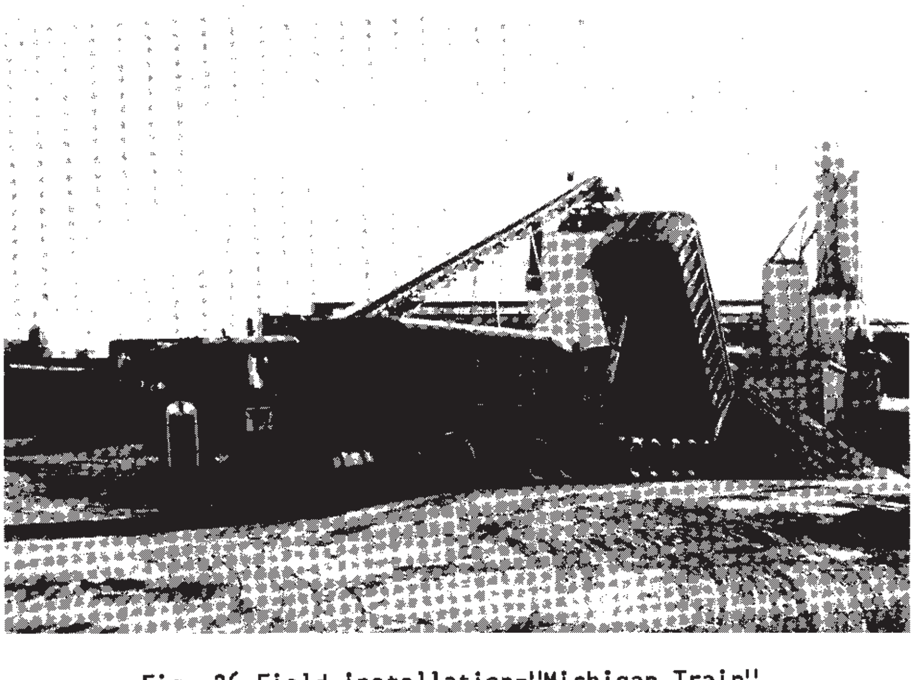

Fig. 26-Field installation-"Michigan Train" urban hauler

that all of the laboratory testing imaginable does not necessarily prove-out a product. The final test is how well it performs in actual applications when subjected to all of the elements which cannot possibly be anticipated and how it is accepted by users who make their "bread and butter" with the product. That phase of testing began with an extensive program which included the installation of 12 experimental units in customer-owned trucks. Applications were selected to include the extremes in both terrain and climatic conditions.

The 12 experimental units accumulated over 3 million miles (4.83 million km) in various applications from an 11 axle "Michigan Train" rig (Fig. 26) hauling sand and gravel into the Detroit area to line haul units operating primarily on Interstate highways (Fig. 27). The transmission in the truck shown accumulated approximately 500,000 miles (804,500 km) behind a 375 HP engine over about a 2 1/2 year period.

Driver and owner reactions were enthusiastic. Drivers liked the 7155 because there was little effort required with the fingertip

Fig. 27-Field installation primarily interstate operation

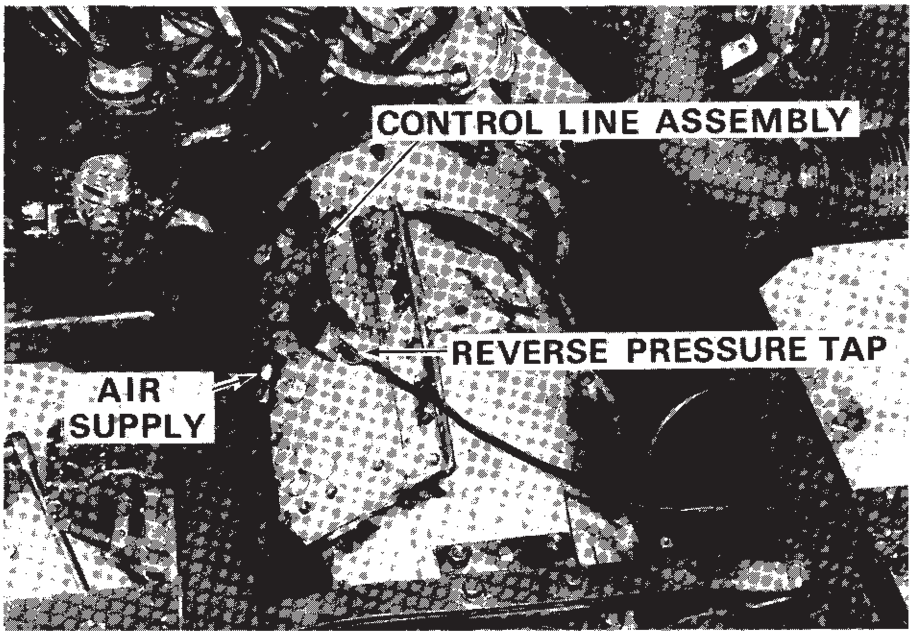

Fig. 28-7155 Installed in a freightliner chassis control and no clutch pedal to operate, they could shift smoothly and dependably in all types of operation, they could concentrate more on driving and less on shifting, they could determine when a shift occurred (no surprises), and they had better trip times in urban and rural areas where driving conditions were less than ideal. Owners liked the units because there was no sacrifice in fuel consumption and a minimum of maintenance was required.

The truck factory contacts were impressed with the simplicity of the installation ... no clutch pedal or associated linkage, no gear shift mechanism with the complex tower on COE models, no heat exchanger or associated oil and water lines. To install the 7155, the drive ring is bolted to a standard flywheel and the transmission is mounted on an SAE No. 1 flywheel housing (Fig. 28). The ratio selector is then installed in the cab with a flexible control line assembly connected from the ratio selector to the transmission control. An air supply line and a standard rear support spring are provided and the installation is complete. Provisions have also been made for oil pressure, temperature, and reverse pressure pickups. The reverse pressure signal is used for back-up lights or warning devices.

SUMMARY

The Caterpillar 7155 Semi-Automatic Heavy-Duty Truck Transmission is a new concept in the evolutionary process of converting the output of a prime mover to the demand of the vehicle. The diesel engine is the current prime mover and appears well intrenched for the heavy-duty truck industry into the future. No drastic changes in the vehicle's general configuration appear in the making at this time. Therefore, the 7155 Transmission is ready to install in any current and future heavy-duty truck.

Since the gears do not dip in the lubricating oil and oil pressure is not used for the controls, the only loss associated with the oil is the small lubricating pump. With this small loss level, the mechanical efficiency is greater than 95%, eliminating the cost and installation of an oil cooler and lines. The design for use with engine oil and "top of frame" oil checking and filling improves the serviceability and maintainability of the 7155 Transmission. Addition of two SAE heavy-duty PTO's, left and right, increases the versatility to cover most auxiliary drive requirements of the trucking industry.

The incorporation of "fingertip" shifting controls and "no clutch pedal" starting has increased the useability of the transmission by unskilled drivers and reduced the effort and concentration requirement of the accomplished drivers. To further help all drivers, the ratio selector lever movement has an inhibiting mechanism that allows upshift movement from neutral to fourth (the normal starting gear for a loaded vehicle on level, hard surface), in two step increments from fourth to eleventh (for accelerating the load), and single stepped from eleventh to sixteenth. The downshift inhibiting is similarly arranged, but any ratio can be used in either direction to match particular supply-demand situations. Lifting the shift lever releases the inhibitor allowing gross ratio changes necessitated by cornering, stops, and unusual conditions.

The mechanically inhibited ratio selector, modulated clutch engagements, and 21% progressive steps serve to reduce strain and abuse on the engine and drive train thus reducing the maintenance requirements of the vehicle. Gears, bearing, and shafts have been designed for the 450 horsepower range with an anticipated "over the road" life of 500,000 miles (804,500 km). The overall reduction of 17.23 to 1 is intended to start the heavier vehicles of today and the near future in all normal and most abnormal conditions.

The 7155 Transmission was designed and developed to increase the heavy-duty truck performance by improving the ratio change technique and reducing the driver's required effort and skill. It is ready to take its place in the industry.

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