

# On Performance of a Two Stage Rotary Snow Blower

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We manufactured two types of augers, a screw and rake type auger and a ribbon screw type auger to further improve the performance of the two stage rotary snow blower that is now considered as the most effective remover in view of the diversified nature of snow in Japan. After installing each of them on a base machine actually used, we examined the performance characteristics while changing revolutions and snow nature. We also prepared two blowers (four-blade blower and five-blade blower) to examine their difference. The results of the test are summarized as follows: (1) 3-element ribbon screw type auger was superior to 2-element screw and rake type auger in general performance. (2) Snow removing performance considerably depends on the combination between blower and auger circumferential speed. Maximum snow removing capacity (t/h) is got at such a combination as the blower speed is low, while the auger speed is high in order to increase the capacity of snow gathering. Blower high speed is provided to get the distance of snow ejection. In this case, low auger speed produces better result. (3) The 4-blade blower was superior in performance to the 5-blade blower. This, however, depends on the volumetric capacity margin of the blower housing.

## Circumstances of Snow Removal from Roads in Japan

Japan is world-famous for its heavy snowfall. As compared with other snowy countries in Europe and America, it is located in low latitudes lying from north to south. The nature of snow, therefore, is diverse because the weather condition varies from one region to another. In Japan, cold and snowy provinces account for 60% of the whole country where about one fourth of the total population live. It is, therefore, very important to provide proper policy to protect roads from snow and ice and to remove snow from roads to ensure smooth traffic in the winter season in such provinces for industrial promotion and stabilization of the people's livelihood.

Mechanization of snow removal from roads in Japan first started in 1945. In those days, however, only

few machines were used and method was immature. As the demand for snow removal grew year after year, studies of methods, improvement of domestic machines, and proto-type manufacturing and research were gradually promoted. Thanks to the Japanese Government's financial aid started from 1957, various projects against snow have been actively promoted in snowy provinces. As a consequence, social and economic activities in the winter season have been remarkably progressed. However, we will not be fully satisfied until we attain social and economic activities in the same level throughout a year by constructing ALL WEATHERED ROADS in the entire area.

The nature of snow is various as it falls, and changes in complexity as it lies on the ground under influence of local weather and traffic conditions. Therefore, we must remove snow with the nature varying in fresh snow, lying snow, removed snow, and snow-drift under various road conditions requiring different methods, such as the road structure and traffic volume. So that many kinds of machines are necessary to cope with any circumstance conceivable.

## Classification of Snow Removing Machines

Snow removing machines are various in their structure, applications, and sizes. They are categorized into four types below.

1. Snow plough
2. Rotary snow blower
3. Snow loader
4. Others

A snow plough is used to remove fresh snow with rapidity, a rotary snow blower to remove snow pushed aside to road shoulder as well as in air fields and railroads, and a snow loader to load snow to a dump truck in narrow roads. These machines have been continuously improved in structure and performance. Meanwhile, rapid expansion of traffic volume in recent years brings about a demand for high efficiency in snow removal. Large-sized high-speed snow removing machines (max. 800 HP class) have been developed to satisfy the demand. Also pressed snow removers to improve the removed snow quality and small-sized machines (100 HP class) for sidewalks

have been developed and successfully utilized.

In Japan in such a background, the typical snow removing machine in use is a two-stage rotary snow blower with a 200 to 300 HP engine. It has only one engine and the snow removing mechanism is mechanically driven.

1. Model Rotary Snow Blower model NR652S
  2. Performance
- Max. snow removing capacity  
(based on JIS D6509 Test Code of Vehicles with Rotary Snow Blower) 1700 t/h
- Max. snow removing width 2600 mm
- Max. snow removing height 1800 mm

General Description of Test

Specifications of Test Machine

Model NR652S rotary snow blower was selected as the base machine for the test. The machine is driven by one engine and adopts 2-way system in which the vehicle is driven hydrostatically during snow removal operation requiring constant low speed and backing. During travelling, it is mechanically driven as general vehicles. The snow removing system consists of two stages; the auger and blower. Figure 1 shows the appearance of the test machine.

Snow ejection distance:

Speed range	1	2	3
Snow ejection distance (m)	18	27	35

Running speed;  
For operation

Speed range	1	2	3
Forward & backward (Km/h)	0-5	0-10	0-17

For travelling

Speed range	1	2	3
Forward (Km/h)	22	30	40
Backward (Km/h)	0-5	0-10	0-17

Figure 1. Appearance of the test machine.

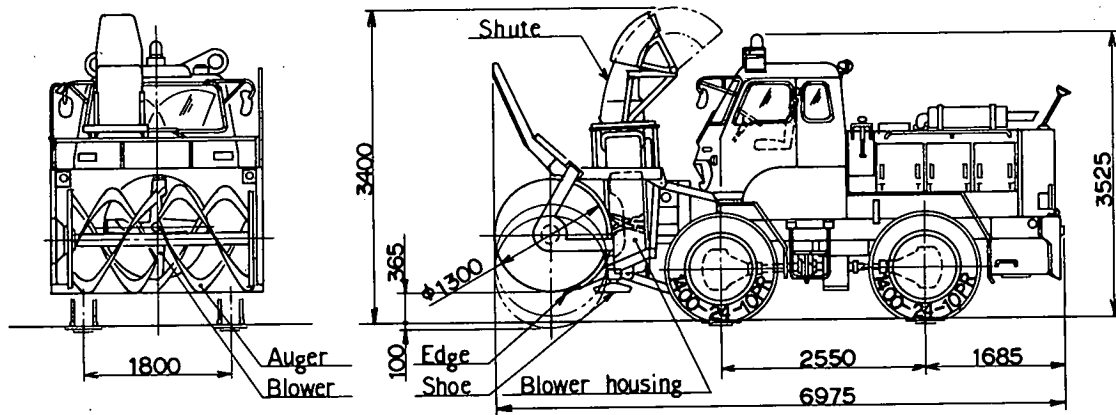
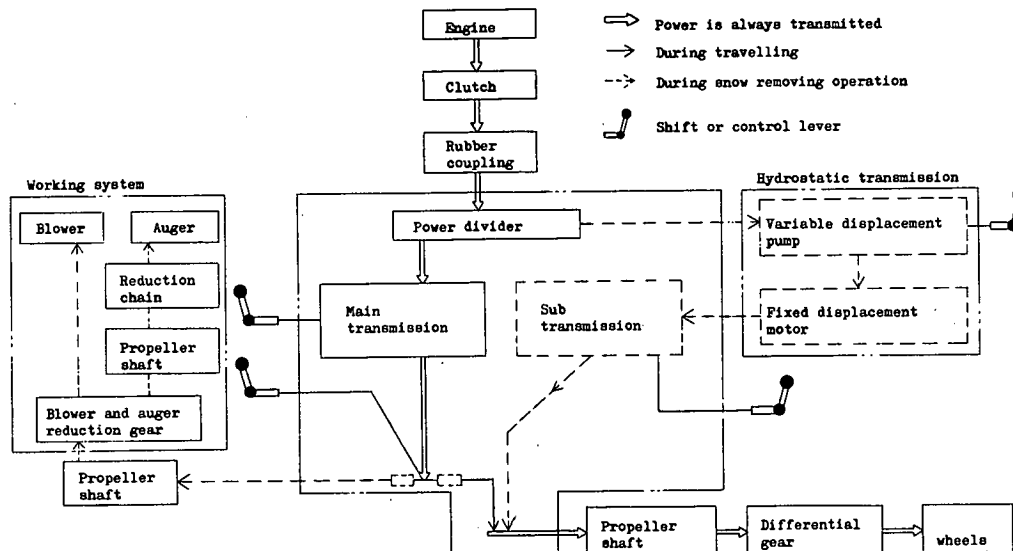


Figure 2. Power transmission flowchart of the test machine.



3. Main dimensions

Overall length	6,975 mm
Overall width	2,600 mm
Overall height	3,525 mm
Minimum ground clearance	300 mm
Weight	
Overall weight (including 2 crew-members)	12,600 kg
Front axle	6,450 kg
Rear axle	6,150 kg
Weight of vehicle	9,540 kg
Weight of snow removing unit	2,950 kg
Crew	2 members

4. Power transmission

Power transmission flowchart is shown in Figure 2.

5. Vehicle

Type	Front wheel steering, one rear engine	
Engine	Nissan Diesel Engine model RD8T	
Rated number of revolutions	2200 rpm	
Rated output	260 HP	
Max. torque	106.5 kgm at 1400 rpm	
Drive system	All - wheel drive (4x4)	

6. Snow removing system

Type Two - stage type

Auger;

Type	Number of screw element	Screw lead (mm)
Screw and rake type	2	1040
Ribbon screw type	3	1700

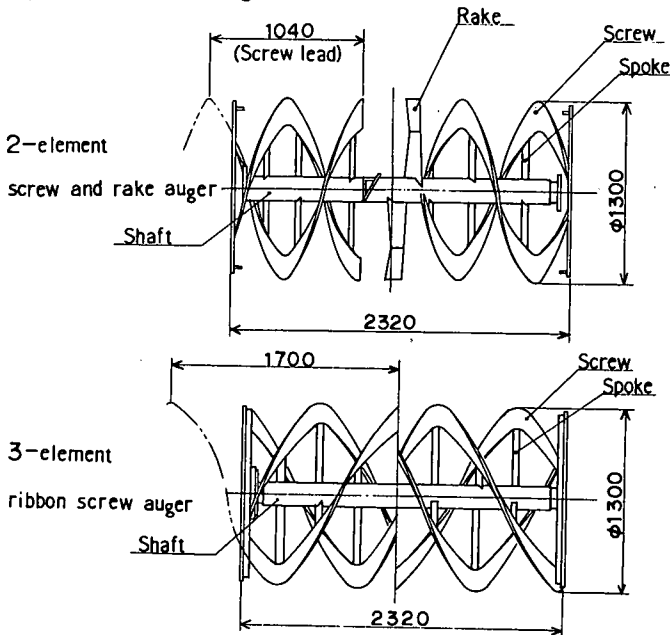
Auger revolution speed (with engine revolving at 2200 rpm) ;

For the test, two auger revolution speeds (High and Low) were provided by changing auger driving chain sprockets.

Speed range	1	2	3
rpm	H 96	129	171
(circumferential speed m/s)	(6.56)	(8.79)	(11.7)
	L 128	172	228
	(8.75)	(11.7)	(15.6)

Two types of tested auger are shown in Figure 3.

Figure 3. Tested augers.



Blower;

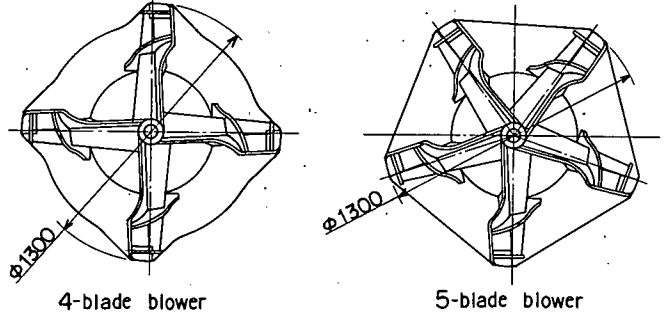
Type	Outside diameter (mm)	Depth (mm)
4-blade blower	1300	500
5-blade blower	1300	500

Blower revolution speed (with engine revolving at 2200 rpm) ;

Speed range	1	2	3
rpm	213	285	387
(circumferential speed m/s)	(14.5)	(19.4)	(25.7)

Two types of tested blower are shown in Figure 4.

Figure 4. Tested blowers.



Test Method:

Table 1. Test period and site

Period	Test site	Nature of snow	Snow density (g/cm <sup>3</sup> )	Snow removing height (cm)
Jan. 11 - 12, '77	Nagaoka	Coarse snow - settled snow	0.36	70 - 90
Jan. 16 - 17, '77	Yamato	Settled snow	0.27	130 - 150
Feb. 9 - 16, '77	Sapporo	New snow	0.22 - 0.30	70 - 80
Mar. 13 - 16, '77	Yamato	Coarse snow - settled snow	0.45	170 - 200

Table 2. Measuring items and instruments.

No.	Measuring items	Instruments
1	Overall torque for working system	Torque meter (Strain gauge type) — Dynamic strain gauge — Graphic meter
2	Auger torque	
3	Number of revolution of propeller shaft for working system	
4	Oil pressure of hydrostatic transmission	Non contact switch — Pressure gauge (Strain gauge type)
5	Snow density	500 cc Samler, Spring balancer
6	Snow temperature	Thermometer
7	Snow hardness	KINOSHITA'S hardness gauge
8	Time	Stop watch
9	Snow ejection distance	Tape measure
10	Snow removing height	Tape measure, Pole

Test Items.

**Blower Performance Test.** For each of 4-blade and 5-blade blowers, observed the snow suction and discharge status while measuring the removed snow quantity.

**Auger Performance Test.** For each of 2-element screw and rake type auger and 3-element ribbon screw type auger, measured the removed snow quantities at H-range and L-range auger speeds.

**Horsepower Measurement.** Blower horsepower, auger horsepower, and running horsepower were measured with respect to each test.

**Snow Quality Measurement (Hardness and Density).** Hardness of snow was measured with Kinoshita's Hardness Gauge which is outlined below.

A thin circular metal C (area  $S \text{ cm}^2$ ) is put on the surface of snow, the hardness of which is to be measured. Rod A with a cylinder B at its bottom is set vertically on the plate C and cylindrical weight W (m kg) with a hole through the center, is dropped from height (h cm) onto B along road A, an impulsive force is applied to snow producing a depression of the snow surface (d cm).

The average resistance  $F$  (kg) which the snow exerts to C is given by

$$F = m(1 + h/d) + M$$

where  $M$  is the sum of the weight of A and C.

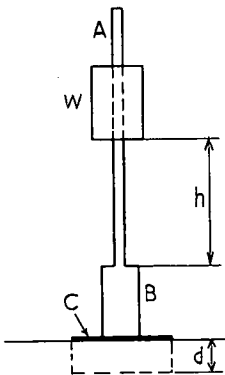
The hardness of snow ( $H \text{ kg/cm}^2$ ) can be defined by

$$H = F / S$$

$$H = 1 / S(m(1+h/d) + M)$$

Circular plates of different diameters are prepared to apply wide range of snow hardness, and to apply to hard packed snow, slender cylindrical pieces (basal area  $S \text{ cm}^2$ ) are attached to the cylinder B instead of plate C.

Figure 5. Kinoshita's hardness gauge



Measurement of Cross Section Area of Snow in front of The Machine.

**Combinations.** Sites with natural snow cover were selected for the test. Each test item was repeated for following combinations.

Table 3. Combinations.

Auger type	Auger speed range	Blower type	Snow removing width
2-element Screw and rake type	High	4-blade	Full (2.6m)
3-element Ribbon screw type	Low	5-blade	Quarter (0.65m)

Test Results and Comments

The total number of measurements throughout the test added up to 290. The results and comments are

given below.

**Blower Performance Rate  $L_B$  (t/HP. h)**

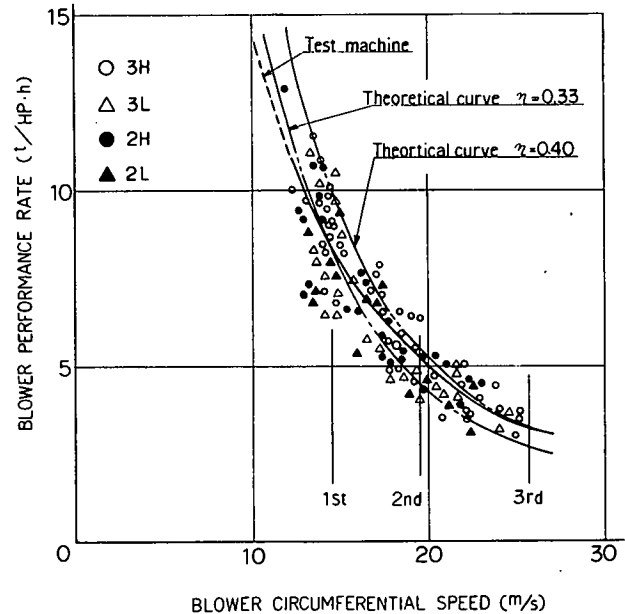
$L_B$  is the gross weight of snow ejected by the blower in an hour per one horsepower. Theoretical  $L_B$  is given by the following formula.

$$L_B = \frac{540g}{V_B^2} \times \eta$$

$g$ : gravitational acceleration  
 $V_B$ : blower circumferential speed  
 $\eta$ : blower volumetric efficiency

Fig. 6 shows the relationships between blower performance rate  $L_B$  and blower circumferential speed  $V_B$ . The value of  $\eta$  in the above formula, therefore, is estimated to be 0.33 - 0.40.

Figure 6. Relation between blower performance rate and blower circumferential speed.



**Overall Snow Removing Performance Rate  $L_o$  (t/HP.h)**

$L_o$  is the gross weight of snow removed by the working system (blower and auger) in an hour per one horsepower.

Figure 7 shows the relationships between  $L_o$  and  $V_B$ .

1. As a general tendency, in the 1st speed range where  $V_B$  is low,  $L_o$  is in proportion to the auger speed while in the 3rd speed range where  $V_B$  is high,  $L_o$  is in reverse proportion to the auger speed. In the 2nd speed range, the difference caused by auger speed difference is minimum. The work efficiencies of different combinations are as follows:

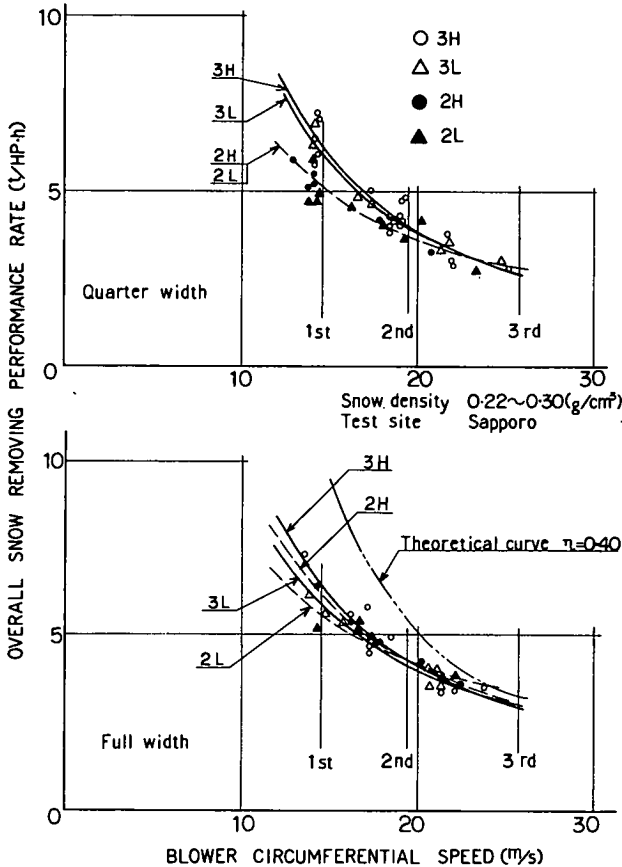
$$3H > 3L \approx 2H \sim 2L \text{ (descending order)}$$

2. Snow removing performance rate  $L_o$  in quarter width as compared with the same in full width operation.

Blower speed range	Quarter width/full width	
	3H	2H
1	0.98	0.85
2	0.95	0.88
3	0.92	0.85

The above table shows that under high-speed revolution the snow removing performance of the 3-element ribbon screw auger drops only 2-8% in quarter width snow removing operation as compared with full width operation.

Figure 7. Relation between overall snow removing performance rate and blower circumferential speed.



Relationship between Blower Performance Rate  $L_B$  and Overall Snow Removing Performance Rate  $L_o$

$L_o$  shows similar tendency for different snow density.  $L_B/L_o$  calculated from the data in Fig. 7 (for 3H in full width operation) are as follows:

- 1st blower speed range  $L_B/L_o = \frac{8.50}{6.45} = 1.32$
- 2nd blower speed range  $L_B/L_o = \frac{5.30}{4.20} = 1.26$
- 3rd blower speed range  $L_B/L_o = \frac{3.25}{2.85} = 1.14$

$L_B/L_o$  for values of  $L_B$  given by theoretical formula

$$L_B = \frac{540g}{v_B^2} \times \eta \quad (\eta = 0.33 - 0.40)$$

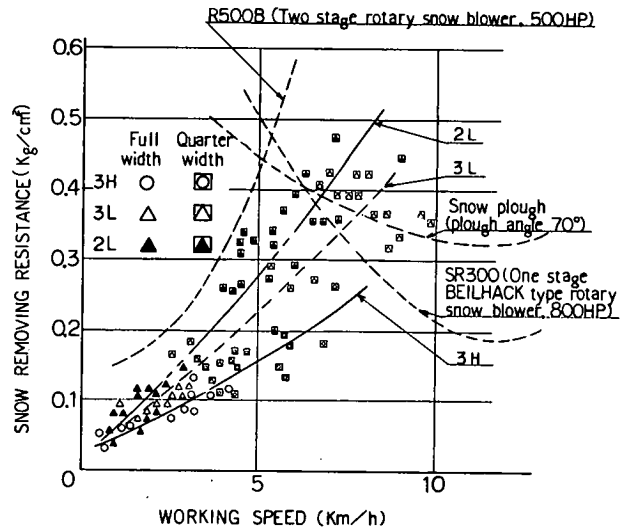
decreases as blower circumferential speed increases.

Snow Removing Resistance  $R$  ( $kg/cm^2$ ) and Working Speed  $U$  (Km/h)

Snow removing resistance  $R$  is given as reaction force (tyre tangential force) per cross section area

of snow removed. Figure 8 shows the relationships between  $R$  and  $U$ . The general tendency of the test machine is different from that of SR-300 (one stage BEILHACK type rotary snow blower, 800HP). It resembles that of R500B (two stage rotary snow blower, 500HP) except that snow removing resistance tends to stay lower. The resistance  $R$  is largest in 3H followed with 3L and 2L in this order. It decreases as the number of screw elements and auger speed increase.  $R$  in two stage type increases as the working speed increases while in BEILHACK type it decreases and reaches the minimum at the working speed of 12 km/h.

Figure 8. Relation between snow removing resistance and working speed.



Maximum Snow Removing Capacity

Table 4 shows such values among the measured data that are considered to be obtained in reasonable operation status. The specified maximum snow removing capacity of the machine is 1700 t/h at snow density of  $\rho = 0.3$ .

As the result of our test, the machine recorded over 1700 t/h in full width operation with 4-blade blower and 3-element ribbon screw type auger at high speed revolution and over 1500 t/h in quarter width operation under the same conditions. (Snow density  $\rho$  was 0.27 - 0.30)

Comparison between 4-blade Blower and 5-blade Blower

Visual observation of flying snow at the blower housing outlet told that the 5-blade blower performance is slightly more continuous. As to the snow removing capacity, however the 5-blade blower was a little inferior. In 3H operation, the snow removing capacity with the 4-blade blower as against the same with the 5-blade blower is as shown below.

Blower speed range	Full width	Quarter width
1	$\frac{1770}{1718} = 1.03$	$\frac{1523}{1268} = 1.20$
2	$\frac{1395}{1184} = 1.18$	$\frac{1177}{1055} = 1.12$
3	$\frac{872}{814} = 1.07$	$\frac{922}{686} = 1.34$

The 4-blade blower increases the snow removing capacity by about 16% in average.  
The ratio of total blade volumes is:

$$\frac{5\text{-blades}}{4\text{-blades}} = \frac{0.0978 \text{ (m}^3\text{)}}{0.0869 \text{ (m}^3\text{)}} = 1.125$$

The ratio of total voids in blower housing is:

$$\frac{\text{Voids of 5-blade blower}}{\text{Voids of 4-blade blower}} = \frac{0.462 \text{ (m}^3\text{)}}{0.473 \text{ (m}^3\text{)}} = 0.98$$

The total voids in the 5-blade blower are only 2% less.

The increase of blade volume of 12.5% in the 5-blade blower is considered to be the cause of reduction of the snow removing capacity.

Table 4. Data of maximum snow removing capacity of the test machine.

Blower type	Combination of auger type and auger speed range	Snow density (g/cm <sup>3</sup> )	Test site	Snow removing capacity (t/h)					
				Full width (2.6m)			Quarter width (0.65m)		
				1st	2nd	3rd	1st	2nd	3rd
4-blade	2L	0.26	Sapporo	1542	1221	868	1242	897	621
		0.28	Yamato	1126	1070	774	1080	1029	710
		0.36	Nagaoka	1521	1057	823	1154	1031	
	2H	0.22	Sapporo	1639	1230	765	1514	1093	715
		0.36	Nagaoka	1632	1121	674	1128	1169	
	3L	0.26	Sapporo	1872	1276	840	1201	1089	839
		0.28	Yamato	1471	1147	800	1251	942	641
	3H	0.27-0.30	Sapporo	1770	1395	872	1523	1177	922
0.28		Yamato	1419	1112	840	1475	1130	857	
5-blade	2H	0.44	Yamato	1595	1232	766	1480	1043	794
	3H	0.26	Sapporo	1718	1184	814	1268	1055	686
		0.45	Yamato	1605	1251	851	1447	1077	747

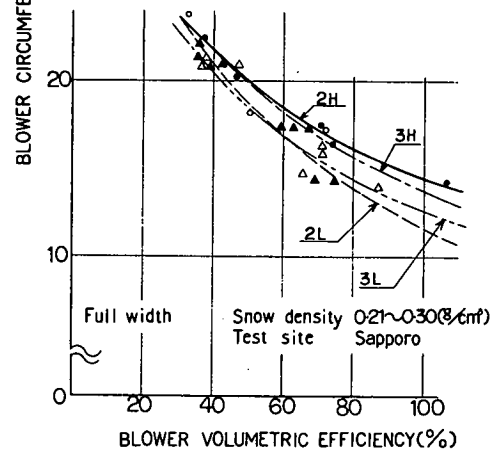
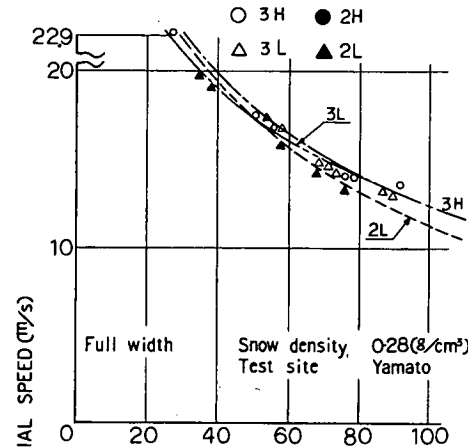
Blower Volumetric Efficiency  $\eta_B$

$\eta_B$  refers to the ratio of actual snow removing capacity to the full blower displacement for a unit hour. Figure 9 shows the relationships between blower volumetric efficiency  $\eta_B$  and blower circumferential speed  $V_B$ .

1. Slower  $V_B$  produces higher  $\eta_B$ . As  $V_B$  increases,  $\eta_B$  decreases because the snow drawn into the blower is accelerated before it reaches the depth of the blower. High circumferential speed, however, is necessary in actual operation.

2. As a general tendency,  $\eta_B$  is higher in high auger speed range (H range) than in low range (L range). The ratio of blower circumferential speed  $V_B$  to auger circumferential speed  $V_A$  is 1.66 in high auger speed range, and is 2.21 in low auger speed range. Thus, matching of  $V_B$  and  $V_A$  is better in high auger speed range.

Figure 9. Relation between blower circumferential speed and blower volumetric efficiency.



Running Horsepower  $P_{sr}$  (HP)

Figure 10 shows the relationships between running horsepower.  $P_{sr}$  is smaller in high auger speed range than in low range. 3-element ribbon screw type auger results in less  $P_{sr}$  than 2-element screw rake type auger.

The following sequence shows the descending order of  $P_{sr}$  for different combinations.

$$2L > 3L \approx 2H > 3H$$

Relationships between  $P_{sr}$  and  $U$  are as follows:

2L	HP $\approx$ 7.0 U
3L	HP $\approx$ 6.2 U
2H	HP $\approx$ 5.5 U
3H	HP $\approx$ 4.5 U

Ratio between different augers are:

$$\frac{2L}{3L} = \frac{7.0U}{6.2U} = 1.13$$

1.17 in average

$$\frac{2H}{3H} = \frac{5.5U}{4.5U} = 1.22$$

Ratio between different speeds are:

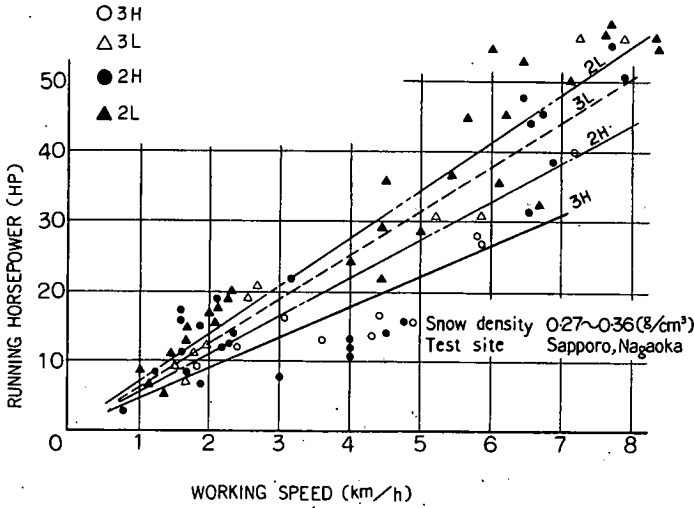
$$\frac{2L}{2H} = \frac{7.0U}{5.5U} = 1.27$$

1.33 in average

$$\frac{3L}{3H} = \frac{6.2U}{4.5U} = 1.38$$

Therefore,  $P_{sr}$  is more affected by auger speed than by auger types.

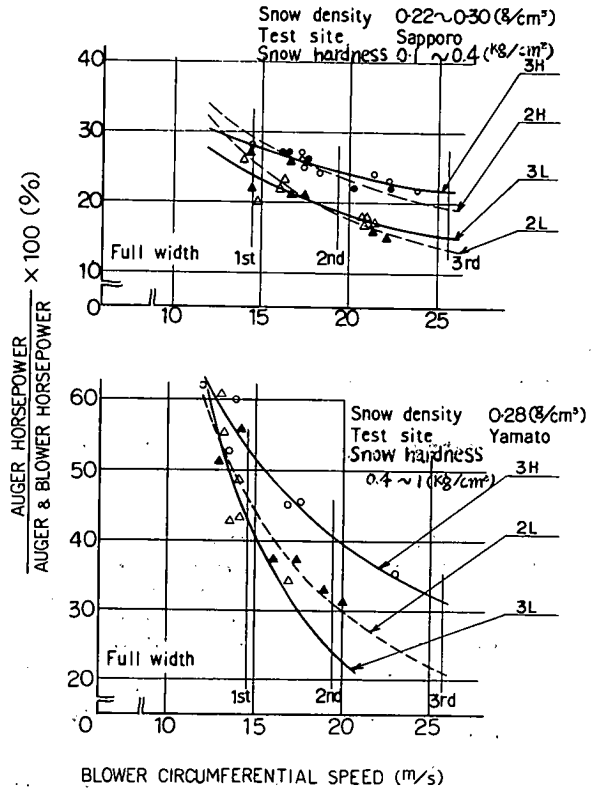
Figure 10. Relation between running horsepower and working speed.



Distribution of Working Horsepower

Figure 11 shows the horsepower distribution between the blower and auger. Although the fresh snow ( $\rho = 0.22 - 0.30$ ) at Sapporo and settled snow ( $\rho = 0.28$ ) at Yamato are almost equal in density, power consumption at Yamato is larger than at Sapporo. The ratio of auger power consumption to overall power consumption is also larger at Yamato. These are considered to be caused by the difference in the nature of snow than by the auger type or speed.

Figure 11. Horsepower distribution between blower and auger.



Reference

Seich Kinoshita. The Hardness of Snow(1). Institute of Low Temperature Science, Hokkaido University, Japan. Series A 19 1960, pp 119-134.