# IMPROVEMENT OF PERFORMANCES OF

# ROTARY SNOW REMOVING WHEEL

Makoto NUNOBE* and Youichirou KAWASAKI**

*TCM Corporation, Development Department
3, Ryugasaki City, Ibaraki Prefecture, Japan
Tel: +81-297-62-5046 / Fax: +81-297-64-5563
E-mail:m_nunobe@mail.tcm.co.jp

**TCM Corporation, Development Department
3, Ryugasaki City, Ibaraki Prefecture, Japan
Tel: +81-297-62-5046 / Fax: +81-297-64-5563
E-mail:y_kawasaki@mail.tcm.co.jp

## 1. Abstract

The motive power of the engine of rotary snow removing wheel is distributed into three: traveling power, auger and blower power of working machine. The motive power of working machine largely depends upon the snow removing conditions. Although some results have so far been reported from certain studies that predicted the motive power of working machine, the results of our tentative examination into the working motive power of a rotary snow removing wheel, one of our products, do not manifest any good coincidence with any reported predictive results. This suggested us a requirement to have tentatively a relationship formula that allows us to predict the motive power of working machine from the snow removing conditions.

This paper concerns the remodeling of a working machine for a small rotary snow removing wheel into a working machine (two stage type) for test to examine the snow removing performance. The auger, blower and traveling unit may be operated individually and independently. The revolutions per minutes and torque of auger and blower were measured under some testing conditions (about 60 conditions of testing data). Based on the measured data, multiple regression analysis was conducted which is a kind of multivariate analysis. As a result, the torques of auger and blower and removed snow weight, which are important elements to know the snow removing performance could be represented by a regression formula with high estimation accuracy including the working conditions (vehicle speed, removed snow width and height), number of revolutions of the auger and blower, snow conditions (density and hardness), pitch and spiral blade number of auger ribbon and number of auger blades.

Our findings include the following:

(1) The increase in snow hardness implies augmented auger torque.
(2) The small number of revolutions of the auger means increased auger torque.
(3) Increased of removed snow weight has a relation with the rise of blower torque.
(4) The growth of the pitch of auger ribbon increases the torque of auger and blower, but the influence on torque of the spiral blade number of auger ribbon and the number of blades of blower is small.

## 2. Introduction

A working machine (scale: 1/3) of 180 kW class rotary snow removing wheel was fabricated to examine tentatively the snow removing performance for improved performance of the wheel.

The equipment is working machine of a general two stage type comprising an auger and a blower, in which the auger, blower and travel unit may be operated by individual motive powers, which are independent of each other.

The test was worked out under a wide range of snow conditions (density and hardness) from new powder snow to crystal sugar-like one, varying the snow removing conditions (vehicle speed, removed snow width and height) as well as the number of revolutions per minute of the auger and blower to measure the snow and snow removing conditions as well as the number of revolutions and torque of the blower and auger. The multiple regression analysis, which is a kind of multivariate analysis was carried out on the data thus measured. The ribbon pitch and spiral blade number were varied for the auger, and number of blades for the blower to compare the performance.

## 3. Testing Equipment and Method

### 3-1 Testing Equipment

The test was conducted using working machine of a two stage type, which was remodeled from a commercially available small snow removing wheel. Fig. 1 illustrates an outline of this testing equipment.

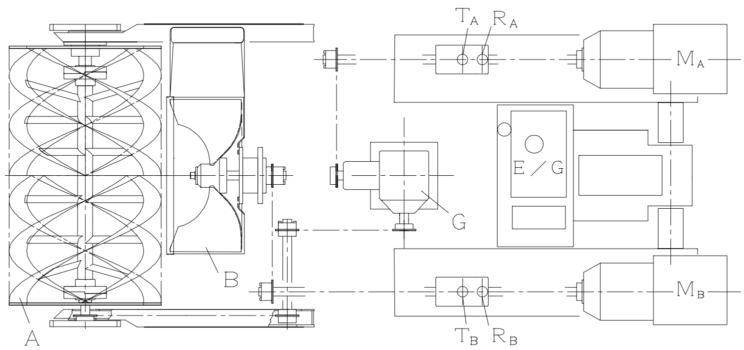


**Fig. 1 Outline of Test Equipment**

The maximum output of the engine of the small snow removing wheel is 6 kW. With HST drive, the speed stage of the clutch is 2. Mainly one speed being used for snow removing work, the vehicle speed may be controllable in terms of the snow removing conditions.

The auger (A) and blower (B) were driven by a motor($M_A$, $M_B$) with reduction gear (output: 2.2 kW/1400 $min^{-1}$, reduction ratio: 1/2). Two units of motors were provided on both sides of engine for independent drive. The driving power for motor was taken from the power supply of an exterior generator (200 V).

The auger and blower can be turned through a drive mechanism consisting of chains and drive shaft. Their respective revolutions per minute were controlled by the inverter of the motor.

The auger and blower as used in the test were fabricated at 1/3 scale of working machine of 180 kW class rotary snow removing wheel. The pitch and spiral blade number were varied for the auger provided for test, and number of blades for blower. (Refer to Table 1)

**Table 1 Geometrical Forms of Auger and Blower**

| Auger (outer dia.: 430 mm) | | | Blower (outer dia.: 430 mm) | |
|---|---|---|---|---|
| Auger No. | Spiral blade number of auger | Pitch of auger ribbon | Blower No. | Number of blower blades |
| 1 | 4 | 350 mm | 1 | 4 |
| 2 | 4 | 570 mm | 2 | 5 |
| 3 | 4 | 775 mm | 3 | 6 |
| 4 | 4 | 955 mm | | |
| 5 | 3 | 462 mm | | |
| 6 | 3 | 868 mm | | |

**3-2 Testing Method**

The respective revolutions per minute and torque of auger and blower were measured with the torque meters ($N_A$, $T_A$, $N_B$, $T_B$ in Fig.1) to be incorporated into the drive shafts arranged in parallel on both sides of engine. The measured data was recorded on the data recorder, whose output was read out on the recording paper as so many waveforms to read the revolution and torque data as numeric value.

In order to annihilate the influence of the traveling resistance on both side edges of auger, the measurement sections were processed into a rectangular solid with the removed snow width within the auger width, and the crawler of the vehicle was so designed as to contact with the ground to avoid any slip while running (test conditions for crystal sugar-like snow).

The removing snow weight was obtained by measuring the distance between the measurement sections, snow width and height and measuring with a stop watch the time from the start of snow removing to its end.

The snow density was acquired by weight measuring method, and snow hardness by KINOSITA method. The snow hardness was measured at three layer faces: near the snow surface, intermediate layer and near the ground. The values thus obtained were then averaged.

**4. Test Results**

**4-1 Testing Conditions**

Table 2 shows the test range of snow removing conditions (vehicle speed, removed snow width and height), number of revolutions per minute of auger and blower, and snow conditions (density and hardness).

**Table 2 Test Conditions**

| | | Crystal sugar-like snow | New powder snow |
|---|---|---|---|
| Revolutions per minute of auger | $min^{-1}$ | 250～350 | 250 |
| Revolutions per minute of blower | $min^{-1}$ | 350～500 | 500 |
| Vehicle speed | km/hour | 0.06～0.5 | 3.0 |
| Removed snow width | cm | 58～73 | 90 |
| Removed snow height | cm | 16～43 | 6.2 |
| Snow density | $g/cm^3$ | 0.4～0.57 | 0.11 |
| Snow hardness | $g/cm^2$ | 410～5,100 | 10.0 |

The snow quality having a great influence on the snow removing performance, a wide range of testing conditions covered all the day long, that is morning, noon and evening when the physical quantity (especially the hardness) of snow varies from new powder snow to crystal sugar-like one.

The testing conditions in this study amounted to 60.

### 4-2 Torque and Removed Snow Weight of Auger and Blower

Except for the motive power for traveling, the motive power of snow removing is consumed as destruction and conveying of snow generated by scratching of auger and carrying power until the snow injection by blower. Figs. 2 and 3 show up the relationship of removed snow weight with the torque of auger and blower, the measurement of motive power. The torque in this case is the net torque without the torque generated at no load.

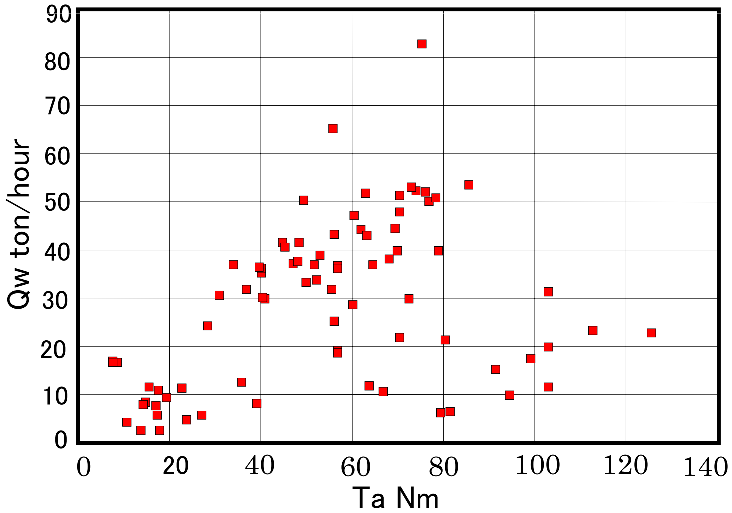


**Fig. 2 Relationship between Auger Torque and Removed Snow Weight**

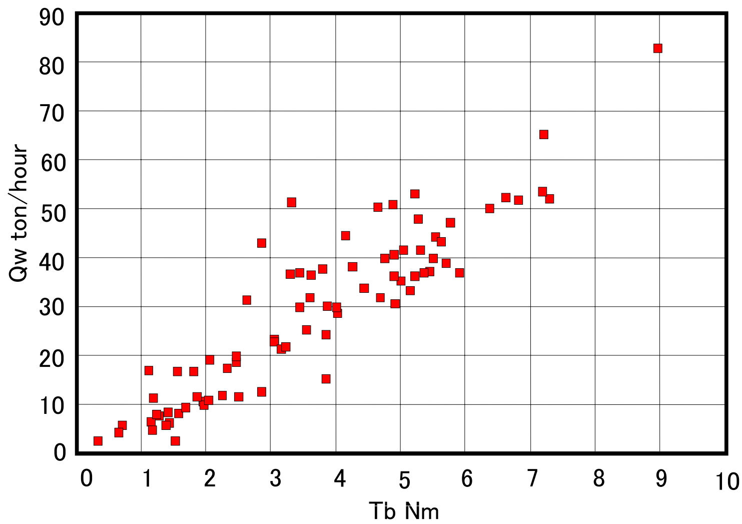


**Fig. 3 Relationship between Blower Torque and Removed Snow Weight**

In the case of auger (Fig. 2), the removed snow weight varying largely depending upon the geometrical form (pitch and spiral blade number) and testing conditions, there is no clear correlation seen between the auger torque and removed snow weight. This is thought to be mainly due to the sharp influence of the snow conditions. In the case of the blower (Fig. 3), however, there is not so much relationship with the geometrical form (number of blades) of the blower nor with the testing conditions. There is an almost positive relationship between the blower torque and the removed snow weight. This implies that the conditions of the snow to be given to the auger do play an important role in the snow removing performance.

**4-3 Estimation by Multiple Regression Analysis**

The data collected as information at the working site of snow removing wheel includes the snow removing conditions (removed snow width, removed snow height, vehicle speed), revolutions per minute of engine (number of revolutions of auger and blower with constant gear ratio taken into account) and snow conditions (density and hardness). If we can have a calculation formula that allows for the prediction of the torque of auger and blower as well as the removed snow weight based on these data, we could know the snow removing performance in terms of the working conditions of snow removing. Based on the data of 60 sorts of testing conditions, we conducted the multiple regression analysis, which is a kind of multivariate analysis to have the regressive estimation formula for auger torque, blower torque and removed snow weight.

As a result of multiple regression of auger torque with the pitch of auger ribbon, revolutions per minute of auger, snow removing conditions and snow conditions (density and hardness), we could regress with 0.934 of contribution factor (2 powers of correlation coefficient: $R^2$). The regression formula is as follows:

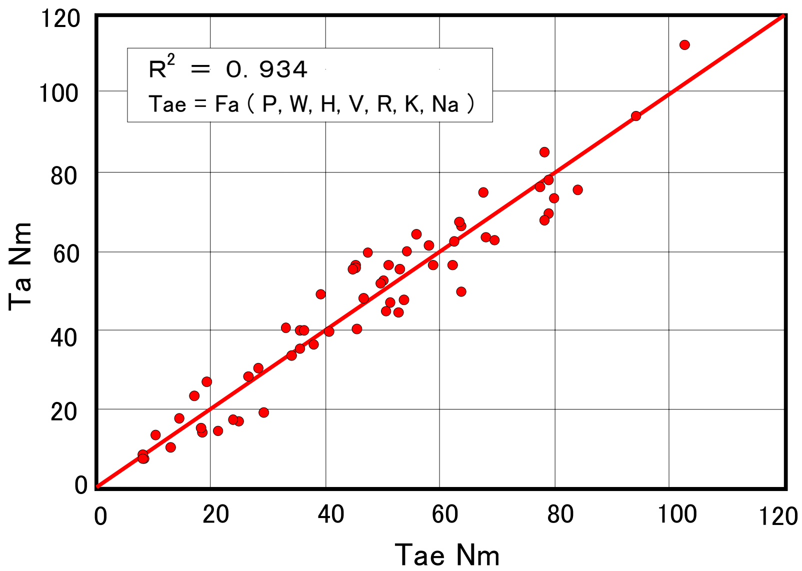


**Fig. 4 Multiple Regression Analysis of Auger Torque**

Tae = Fa (P, W, H, V, R, K, Na)

$$= e^{-7.196} – Pa^{0.588} – W^{1.172} – H^{0.67} – V^{0.897} – R^{0.287} – K^{0.41} – Na^{-0.728} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, Tae: Estimated torque of auger (Nm), P: Pitch of auger ribbon (mm), W: Removed snow width (cm), H: Removed snow height (m), V: Vehicle speed (km/hr), R: Snow density ($g/cm^3$), K: Snow hardness ($g/cm^2$), Na: Revolutions per minute of auger ($/min^{-1}$), and e: exponential constant.

The blower torque could be multi-regressed with the pitch of auger ribbon, revolutions per minute of blower, snow removing conditions and snow conditions (density) of auger torque, resulting in 0.955 contribution coefficient as shown in Fig. 5. The regressive estimation formula is as shown below:

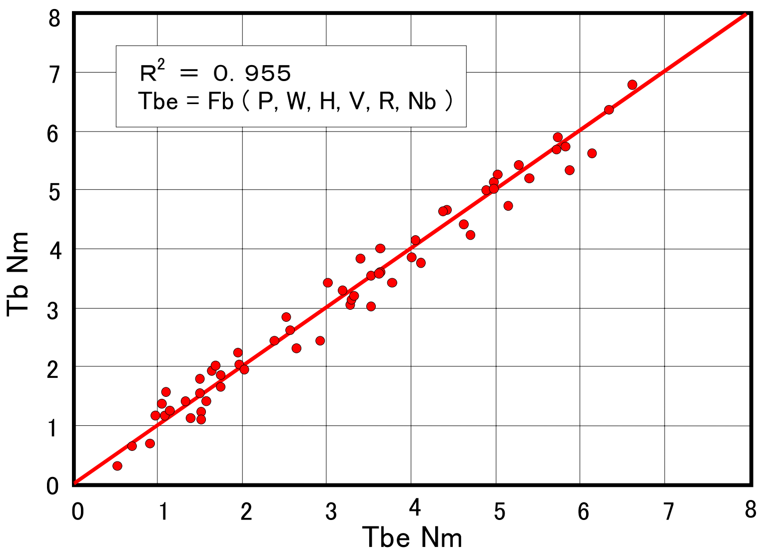


**Fig. 5 Multiple Regression of Blower Torque**

Tbe = Fb (P, W, H, V, R, Nb)

$$= e^{-15.187} – Pa^{0.297} – W^{1.066} – H^{1.259} – V^{0.857} – R^{0.682} – Nb^{-0.449} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, Tbe: Estimated torque of blower (Nm), and Nb: Revolutions per minute of blower ($min^{-1}$).

As a result of multiple regression of snow removing weight with the number of blower blades, auger torque, revolutions per minute of blower, blower torque, snow removing conditions, and snow conditions (density and hardness), we could regress with 0.990 contribution coefficient as shown in Fig. 6. The regressive estimation formula is as follows:

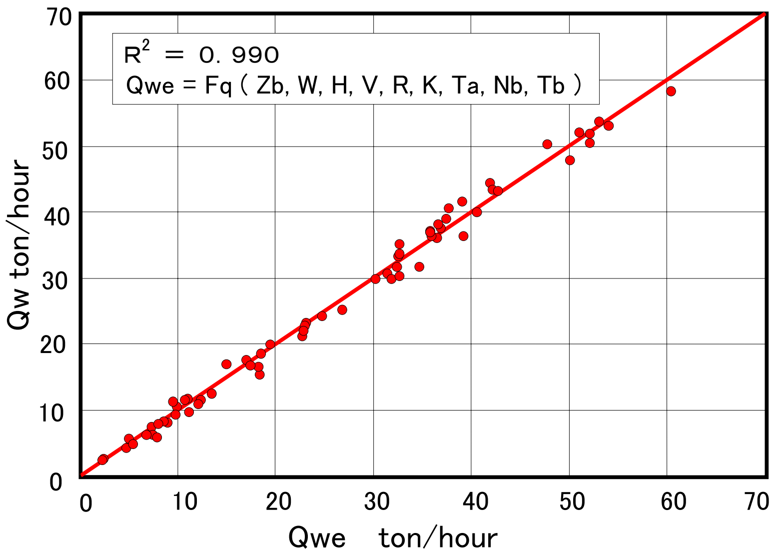


**Fig. 6 Multiple Regression of Removed Snow Weight**

Qwe = Fq (Zb, W, H, V, R, K, Ta, Nb, Tb)

$$= e^{2.058} - Zb^{-0.284} - W^{0.971} - H^{0.515} - V^{0.649} - R^{0.604} - K^{0.071} - Ta^{-0.16} - Nb^{-0.028} - Tb^{0.468} \quad \text{.........................} (3)$$

Where, Qwe: Estimated removed snow weight (ton/hr), Zb: Number of blower blades, Ta: Auger torque (Nm), and Tb: Blower torque (Nm).

The estimated removed snow weight may be obtained substituting the estimated torque of auger and blower obtained from the formulas (1) and (2) with the formula (3).

## 5. Conclusion

We could represent, by a regression formula with sufficiently high estimated accuracy, the auger torque, blower torque and removed snow weight, which are important elements to know the snow removing performance against about 60 sorts of test condition data. Our findings are as follows:

(1) The increase of snow hardness means increased auger torque.
(2) Smaller number of revolutions of auger and increased cutting depth of auger ribbon increases the auger torque.
(3) The higher pitch of auger ribbon relates to the increased torque of blower and auger.
(4) Increased removed snow weight relates to the increased blower torque.
(5) Variation in spiral blade number of auger ribbon and number of blower blades has little impact on the torque of auger or blower.