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**Quality characteristics of products—
General rules for determination of
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**Quality characteristics of products—
General rules for determination of specific values**

1 Scope This Japanese Industrial Standard specifies the general rules for the determination of the specific values of the quality characteristics of outgoing goods (1) by considering the required condition and economics.

Note (1) Final products or semi-finished products manufactured by a certain means or through processing for the purpose of commercial dealings.

Remarks 1 The specific values of individual product are shown by both the maximum allowable limit (upper specification limit) and the minimum allowable limit (lower specification limit), specified either by bilateral limits, or by unilateral limit. The maximum allowable limit and the minimum allowable limit are called specification limits. The difference between the nominal value and the specification limits is called tolerance.

2 The specifications described in catalogs or operating instructions are not applicable in this Standard since these specifications are determined by the manufacturers considering the requests or demands of the purchaser and the general public.

3 The following standards are cited in this Standard:

JIS Z 8101 *Glossary of terms used in quality control*

JIS Z 8103 *Glossary of terms used in instrumentation*

2 Definitions and symbols For the purposes of this Standard, in addition to the definitions and symbols given in JIS Z 8101 and JIS Z 8103, the following definitions and symbols apply:

(1) **smaller-is-better characteristic** A characteristic without negative values, 0 is the ideal and the value is considered smaller the better. The specification is shown by the maximum allowable limit and symbol (Δ) is used (i.e., not more than Δ).

Examples: geometrical deviation (e.g., circularity, parallelism or positional deviation), sphericalness of a steel ball, or audible noise level.

(2) **nominal-is-best characteristic** A characteristic with a nominal value (m_0), upper tolerance ($+\Delta$) and lower tolerance ($-\Delta$). It is shown by ($m_0 \pm \Delta$). Many quality characteristics are of this type.

Remarks: Nominal-is-best is the characteristic when the nominal value is desirable in general.

Example: dimension (length or angle)

- (3) **larger-is-better characteristic** A characteristic without negative values and the value is considered larger-the-better. Its specific value is shown by the minimum allowable value and symbol (Δ) is used (i.e., not less than Δ).

Examples: yield strength, impact strength

Remarks: In the case of fraction or percentage, whose values are within the range from 0 to 1 (or from 0% to 100%), these values are transformed into smaller-is-better, nominal-is-best or larger-is-better characteristics.

Example: The degree of cross linking, p , is transformed into $-10 \log (1/p - 1)$.

- (4) **producer** One who manufactures products.
- (5) **user** One who uses a product for its intended purpose.
- (6) **functional limit (Δ_0)** The limit at which a product does not function during its usage.
- (7) **average loss (A_0)** The average of losses incurred when the actual value of a product quality level (hereafter referred to as characteristic) exceeds its functional limit during the usage. The loss is determined in monetary units.
- (8) **producer's loss (A)** The loss incurred to the producer when a characteristic exceeds its specification limit (in monetary units).
- (9) **proportional constant (k)** The constant indicating the economic loss calculated from average loss, A_0 and the square of functional limit, Δ_0 by the following equation:

For nominal-is-best or smaller-is-better characteristic

$$k = \frac{A_0}{\Delta_0^2}$$

For larger-is-better characteristic

$$k = A_0 \Delta_0^2$$

3 Determination of specific values

3.1 Determination of functional limit Δ_0 and average loss A_0

3.1.1 Classification of products Products are classified into the following three categories depending on their usage:

- (1) **Final products** Those which are generally used as finished products.
- (2) **Component parts and semi-finished products** Those which are assembled to be final products.
- (3) **Materials** Raw materials or materials for (1) or (2).

Remarks: Δ_0 and A_0 are specified for the cases (1), (2) or (3) respectively.

3.1.2 Determination of the functional limit Δ_0 and average loss A_0 for final products The functional limit and the average loss for final products are determined as follows:

- (1) The functional limit Δ_0 under normal usage condition (such as the conditions described in operating instructions) is determined. To determine this limit, only one test may be good enough. A_0 is determined from the average loss per unit product when the product did not function in the market. The loss includes the actual damage incurred and the cost of handling claims.
- (2) When specific values are shown in public regulations or catalogs, those values are used as functional limits Δ_0 .
 A_0 is determined from the average loss per unit product handling with recall or claims.

3.1.3 Determination of the functional limit Δ_0 and average loss A_0 for component parts and semi-finished products The functional limit and the average loss for component parts and semi-finished products are determined as follows:

- (1) When the characteristic of a component part and a semi-finished product affects the characteristic of the final product, the value of component part and semi-finished product at which the characteristic of final product exceeds its limit is used as the functional limit Δ_0 . The limit is determined by the test where other component parts and tested conditions are taken as nominal values or normal conditions. The average cost of component part and semi-finished product is used as A_0 when the characteristic of final products exceeds their specific value.
- (2) When a component part and a semi-finished product cause trouble in the market independently from other component parts, or when there exists any specific values in public regulations or catalogs, the functional limit Δ_0 is determined by 3.1.2.

A_0 is also determined by 3.1.2.

3.1.4 Determination of Δ_0 and A_0 for materials The functional limit and the average loss of materials are determined as follows:

- (1) When the place of shipment is known, the limit at which trouble occurs at the shipment site is used as the functional limit Δ_0 . The functional limit Δ_0 is determined under the standard conditions of the chemicals, raw materials or other conditions at the shipment site.

A_0 is the loss caused by exceeding the functional limit at the shipment site.

- (2) When specific values are shown in public regulations or catalogs, those values are used as functional limits Δ_0 . A_0 is determined by the loss per unit product caused by either recall or claims when it is found that the product is out of specification.

3.2 Procedures for determining specific values The procedures for determining specific values are as follows:

Procedure 1 Estimation of functional limit Δ_0 and average loss A_0
 Estimate the functional limit Δ_0 and the average loss A_0 in user's side.

Remarks 1 It is all right in many cases to use a rough estimate for the functional limit Δ_0 and the average loss A_0 .

- 2 In the nominal-is-best characteristic when the functional limit Δ_0 and the average loss A_0 are different on plus and minus sides, these are separately determined for plus and minus sides. The loss may also be determined by using the one with the larger proportional constant k for both sides.

Procedure 2 Estimation of the loss A caused by the producer When the value of a characteristic of a product is outside the specification limits, the loss caused by the producer is estimated as follows:

- (1) If repairing is possible, use the average cost of repair as the loss.
- (2) If repairing is impossible or infeasible, use the average cost of replacing a product and scrapping as the loss.

Remarks: For the producer's loss A , it is desirable that a certain level of optimization is completed by following the procedures described in Annex 1.

Procedure 3 Investigation of quality level and measurement capability For the estimation of producer's loss A , investigate the manufacturable quality level of the component whose specific values are to be determined by applying the methods described in Annex 2. Also investigate if the measurement capability is good enough for the assessment, otherwise improvement must be made by applying the methods described in Annex 3.

Procedure 4 Calculation of Δ Δ is calculated by the following equations:

For nominal-is-best or smaller-is-better characteristic

$$\Delta = \sqrt{\frac{A}{A_0}} \times \Delta_0$$

For larger-is-better characteristic

$$\Delta = \sqrt{\frac{A_0}{A}} \times \Delta_0$$

Procedure 5 Investigation of Δ From the results of procedures 1, 2 and 3, if the process capability cannot meet the specific values after determined by procedure 4, re-calculate Δ by varying the value of A .

- (1) No re-calculation of A and Δ is made if the quality level is adequate.
- (2) If the quality level is not high enough and if the fraction defective (p) can be determined, adjust the producer's loss A then re-calculate Δ .

$$\text{Adjusted } A = \frac{A}{1-p}$$

If the quality level still cannot meet the above specific values and no more improvement is possible, either conduct 100% inspection, change the material or re-design the component part following Annex 2. Or use the Δ determined from procedures 4 and 5 (2) as a tentative value, control the process if necessary.

Procedure 6 Determination of Δ Determine Δ based on the investigation of procedure 5.

Example 1 Smaller-is-better characteristic: Bearing of audio equipment
A bearing made from a high polymer is installed to a metal component in an audio equipment. When the roundness of this bearing exceeds 110 μm , it is estimated that the variation of rotating speed would result 50% of the users to take actions for service. Its cost of repair is 5000 yen.

Procedure 1 Estimation of functional limit Δ_0 and average loss A_0

On the user's side:

Functional limit $\Delta_0 = 110 \mu\text{m}$,

Average loss: $A_0 = 5000 \text{ yen}$

Procedure 2 Estimation of producer's loss A Estimate the producer's loss A from the cost of component to be 700 yen.

Procedure 4 Calculation of maximum allowable limit Δ

Since $\Delta_0 = 110 \mu\text{m}$, $A_0 = 5000 \text{ yen}$ and

$A = 700 \text{ yen}$,

$$\Delta = \sqrt{\frac{700}{5000}} \times 110 \approx 41 (\mu\text{m})$$

Procedure 6 Determination of maximum allowable limit Δ
From the above calculation, calculate the maximum allowable limit of roundness to be 40 μm after rounding the number.

Example 2 Larger-is-better characteristic: Brief case handle A metal component part is inserted into the handle to assemble a brief case. When inserting strength is not more than 150 N, 50% of the users ask for repair because of trouble. Its repairing cost is 5000 yen including handling charge.

Procedure 1 Estimation of functional limit Δ_0 and average loss A_0

On the user's side:

Functional limit $\Delta_0 = 150 \text{ N}$,

Average loss: $A_0 = 5000 \text{ yen}$

Procedure 2 Estimation of producer's loss A The producer's loss is estimated to be 140 yen such as the purchased price of component.

Procedure 4 Calculation of minimum allowable limit Δ

Since $\Delta_0 = 150 \text{ N}$, $A_0 = 5000 \text{ yen}$ and

$A = 140 \text{ yen}$,

$$\Delta = \sqrt{\frac{5000}{140}} \times 150 \approx 896 (\text{N})$$

Procedure 6 Determination of minimum allowable limit Δ
From the above calculation, the minimum allowable limit Δ is determined to be 900 N after rounding the number.

Annex 1 Balancing product quality level and cost

1 Scope This Annex specifies the method to balance the quality level and cost of a product prior to the determination of product quality specific values.

Remarks: Balancing product quality and cost is a method to select one out of several candidates when many product elements or materials are available to be chosen: the goal is to select the one which minimizes overall loss (L_T), the sum of user's loss due to product quality variation after shipment⁽¹⁾ and the cost of acquiring the product⁽²⁾.

Notes (1) Quality variation due to time such as deterioration or wear after shipment, and quality variation due to environmental changes such as temperature or humidity.

(2) The cost of acquiring the selected candidate.

2 Definitions and symbols For the purposes of this Annex, in addition to the definitions and symbols given in the body of this Standard, the following definitions and symbols apply:

total of mean squared errors σ_T^2 Total of the mean squared errors of quality characteristics after shipment. It does not include the quality variation due to manufacturing.

3 Procedures for balancing product quality and cost From several candidates which satisfy the specific values of quality characteristics, compare the total of the loss due to the variation after shipment and the cost of acquiring the product, and select the one which minimizes the total loss. Use the following procedures:

Procedure 1 Select several candidates which may satisfy the specific values of a product consisted of component parts, elements or units, or materials.

Procedure 2 Collect the information regarding the acquired costs of selected candidates and the variations after shipment.

Procedure 3 Select the Loss Function which corresponds to a quality characteristic.

(1) Smaller-is-better or nominal-is-best characteristic

$$\text{Loss } L = \frac{A_0}{\Delta_0^2} \sigma_T^2,$$

where σ_T^2 is the mean squared deviation of the characteristic from the ideal value or the nominal value after shipment.

(2) Larger-is-better characteristic

$$\text{Loss } L = A_0 \Delta_0^2 \sigma_T^2,$$

where σ_T^2 is the mean square of the reciprocal of the characteristic after shipment.

Procedure 4 Find the functional limit Δ_0 and the average loss A_0 .

Procedure 5 Forecast the total of the mean squared errors σ_T^2 for the selected candidate.

When quality characteristic varies during the usage due to deterioration, wear, temperature, humidity, etc., calculate its σ_T^2 as follows:

Letting the changed value of a product characteristic after shipment due to deterioration by time t be denoted by y_d , the changed value due to wear be y_a , and the changed value due to environmental changes (for example, from temperature θ_1 to θ_2) by y_n , calculate the total of mean squared errors σ_T^2 .

$$\begin{aligned}\sigma_T^2 = & \text{(mean squared error due to deterioration)} \\ & + \text{(mean squared error due to wear)} \\ & + \text{(mean squared error due to environmental change)}\end{aligned}$$

(1) Smaller-is-better characteristic

$$\sigma_T^2 = \frac{1}{T} \int_0^T y_d^2 dt + \frac{1}{T} \int_0^T y_a^2 dt + \frac{1}{(\theta_2 - \theta_1)} \int_{\theta_1}^{\theta_2} y_n^2 dn$$

(2) Nominal-is-best characteristic

$$\sigma_T^2 = \frac{1}{T} \int_0^T (y_d - m_0)^2 dt + \frac{1}{T} \int_0^T (y_a - m_0)^2 dt + \frac{1}{(\theta_2 - \theta_1)} \int_{\theta_1}^{\theta_2} (y_n - m_0)^2 dn,$$

where T is the designed product life. In the actual calculation, find T , y_d , y_a , and y_n from the characteristic change curves.

(3) Larger-is-better characteristic

$$\begin{aligned}\text{Total of mean squared errors } \sigma_T^2 \\ = & \text{(mean squared value of the reciprocal of} \\ & \text{characteristic due to deterioration)} \\ & + \text{(mean squared value of the reciprocal of} \\ & \text{characteristic due to wear)} \\ & + \text{(mean squared value of the reciprocal of} \\ & \text{characteristic due to temperature)}\end{aligned}$$

Therefore,

$$\sigma_T^2 = \frac{1}{T} \int_0^T \left(\frac{1}{y_d}\right)^2 dt + \frac{1}{T} \int_0^T \left(\frac{1}{y_a}\right)^2 dt + \frac{1}{(\theta_2 - \theta_1)} \int_{\theta_1}^{\theta_2} \left(\frac{1}{y_n}\right)^2 dn$$

In the actual calculation, find T , y_d , y_a and y_n from the characteristic change curves.

Procedure 6 Calculate the loss due to the total of mean squared errors σ_T^2 .

Procedure 7 Calculate the overall loss L_T from the acquired cost and the total of mean squared errors σ_T^2 . Economic comparison is made and select the one with the smallest overall loss.

Example 1 The case of nominal-is-best A pulley in a precision machine is used for example. The function of this pulley is to provide a constant speed to a component part which moves linearly by a rope surrounding the outer diameter of the pulley. The variation of the outer diameter of pulley affects the variation of the function.

Procedure 1 The nominal value of the outer diameter was determined as 48 mm by design. Several material types are considered. Among those, 3 plastics, 1 aluminum and 1 sintered alloy material were selected as the candidates.

Procedure 2 From the 5 material types, collect the information regarding the variations after shipment and the acquired costs. From the design viewpoint, forecast the wear of outer diameter and the heat expansion due to temperature change as the variations after shipment. The wear of outer diameter is caused by the rope pressure and friction when the rope repeatedly pulls the moving components. Measure the outer diameter wear at designed life test.

In order to estimate the outer diameter change due to heat expansion, find the standard deviation of surrounding temperature change and thermal expansion coefficients, as shown in Annex 1 Table 1.

Measure the standard deviation of temperature variation inside the machine τ to be 7.5°C.

Procedure 3 Calculate the loss due to variations. Since this is the nominal-is-best characteristic, its Loss Function is used.

$$L = \frac{A_0}{A_0^2} \sigma_T^2$$

Annex 1 Table 1 Variations and cost of each candidate

Candidate (material)	Amount of wear B (mm) (at designed life)	Thermal expansion coefficient b ($10^{-6} \text{ } ^\circ\text{C}^{-1}$)	Cost A (yen)
ABS molded product	0.050	100	100
Glass/polycarbonate molded product	0.015	28	180
Polyacetal molded product	0.030	81	130
Aluminum machined product	0.009	23	250
Sintered alloy + machined product	0.010	12	310

Procedure 4 Determine the functional limit Δ_0 and the user's average loss A_0 at the time. When the pulley radius changes, the speed of moving part changes resulting in functional trouble. The functional trouble occurs when the outer diameter varies ± 0.28 mm, i.e., Δ_0 is equal to 0.28. When the functional trouble occurs during the usage, an exchange or repairing of the component is required. The loss is forecasted to be 24000 yen including the cost of component, engineering service and per diem, etc. A_0 is therefore equal to 24000 yen.

Procedure 5 Find the total of mean squared errors σ_T^2 . In this example, there are variations including outer diameter change due to wear and temperature changes. Therefore, the mean squared error due to wear σ_a^2 and the mean squared error due to temperature change σ_θ^2 are added to result in the total.

$$\text{Total of mean squared errors} \quad \sigma_T^2 = \sigma_a^2 + \sigma_\theta^2$$

- (1) The mean squared error of wear σ_a^2 is calculated assuming that the wear of the outer diameter is proportional to the number of usage times. Letting the amount of wear per unit usage time be β , designed life be T and the amount of wear at designed life be B , their relationship is written as

$$\sigma_a^2 = \frac{1}{T} \int_0^T (\beta t)^2 dt = \frac{\beta^2 T^2}{3} = \frac{B^2}{3}$$

- (2) The mean squared error of the outer diameter due to temperature change σ_θ^2 is caused by the environmental temperature change. Calculate it by multiplying the pulley radius r , the linear expansion coefficient b and the standard deviation of temperature change in the machine τ .

$$\sigma_\theta^2 = (b r \tau)^2$$

Procedure 6 The loss is calculated from the data in Annex 1 Table 1. In the case of ABS molded product for example, estimate change in outer diameter due to the wear and the linear expansion coefficient to be 0.05 and 0.0001/°C respectively.

Also, estimate the standard deviation of temperature change in the machine τ to be 7.5°C. Calculate the loss due to variation by

$$\begin{aligned} L &= \frac{A_0}{\Delta_0^2} \sigma_T^2 \\ &= \frac{24\,000}{0.28^2} \left[\frac{0.05^2}{3} + (0.0001 \times 7.5 \times 24)^2 \right] = 354.3 \text{ (yen)} \end{aligned}$$

Similarly calculate the losses of other candidates.

Procedure 7 Calculate the total loss of each candidate L_T by summarizing the loss due to variation L and acquiring cost A as shown in Annex 1 Table 2.

Annex 1 Table 2 Calculation example of loss cost and overall loss

Unit: yen

Candidate (material)	Loss L	Cost A	Overall loss L_T
ABS molded product	354	100	454
Glass/polycarbonate molded product	31	180	211
Polyacetal molded product	157	130	287
Aluminum machined product	14	250	264
Sintered product + machined product	12	310	322

From the results of calculation, glass/polycarbonate molded product has the smallest loss.

Example 2 Larger-is-better characteristic The withstand voltage of aluminium electrolytic condensers for output +5 V constant voltage power source is used as an example. Since withstand voltage is considered higher the better, the case of larger-is-better is applied.

Procedure 1 The types and initial withstand voltage characteristic of aluminium electrolytic condensers available for purchase are shown in Annex 1 Table 3.

Annex 1 Table 3 Condenser types and their characteristic

Candidate	Withstand voltage V_0 (V)	Coefficient of deterioration at 5 V $d \times 10^{-5}$ (1/h)	Cost (yen)
A	16	2.230	100
B	25	1.530	120
C	50	0.852	195
D	63	0.701	230
E	100	0.475	305

Procedure 2 The withstand voltage characteristic of condensers deteriorates during usage. Assuming the coefficient of deterioration is proportional to the ratio of applied voltage and rated voltage, the forecasted values are shown in Annex 1 Table 3.

Procedure 3 Select the Loss Function equation. Since withstand voltage is considered higher the better, the equation for larger-is-better is used.

$$L = A_0 \mathcal{A}_0^2 \sigma_T^2$$

Procedure 4 Find the functional limit Δ_0 and average loss A_0 . The rated output voltage +5V is considered to be the functional limit Δ_0 . It means that when the withstand voltage becomes lower than this value, the condenser will be damaged. When the condenser is broken, the power source printed circuit board should be exchanged. The average loss A_0 is the cost of service including component parts. Detail of the loss is shown as follows:

Component parts:	(Constant voltage power source printed circuit board):	3000 yen
Repairing:		5000 yen
Miscellaneous:		2500 yen
Total		10500 yen

Procedure 5 Calculate the total of mean squared errors σ_T^2 . Since it is the larger-is-better case, the total of mean square errors is calculated from the mean square of the reciprocal of deteriorated withstand voltage of the condenser. Letting the coefficient of deterioration be d , total usage time be T and initial withstand voltage be V_0 , the total is calculated by

$$\sigma_T^2 = \frac{1}{T} \int_0^T \left(\frac{1}{V_0 e^{-dt}} \right)^2 dt = \frac{1}{V_0^2 T} \int_0^T e^{2dt} dt = \frac{1}{2 d V_0^2 T} (e^{2dT} - 1)$$

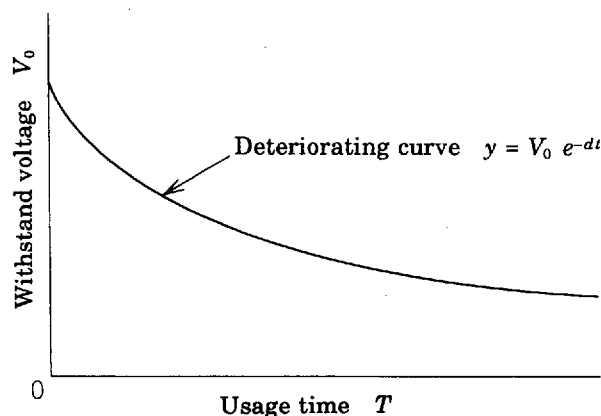
Procedure 6 Put the collected data in the equation to calculate the loss due to variation. In the case of candidate A for example, the initial withstand voltage is 16 V, the designed life T is 5 years and it is used 8 h per day. The designed life is therefore 9600 h. The total of mean squared errors is

$$\sigma_T^2 = \frac{e^{2dT} - 1}{2 d V_0^2 T} = \frac{e^{2 \times 2.23 \times 10^{-5} \times 9600} - 1}{2 \times 2.23 \times 10^{-5} \times 16^2 \times 9600} = \frac{1}{205.1}$$

Calculate the loss L due to variation by

$$L = A_0 \Delta_0^2 \sigma_T^2 = 10500 \times 5^2 \times \frac{1}{205.1} = \frac{262500}{205.1} = 1280$$

Similarly calculate the losses of other candidates.



Annex 1 Fig. 1 Deterioration of withstand voltage

Procedure 7 Calculate the sum of the loss due to variation L and acquiring cost A to be the total loss L_T . Results are shown in Annex 1 Table 4.

Annex 1 Table 4 Calculated total loss

Unit: yen

Candidate	Loss L	Cost A	Total loss L_T
A	1 280	100	1 380
B	488	120	608
C	114	195	309
D	71	230	301
E	27	305	333

From the results, candidate D is selected.

In the case of smaller-is-better, use similar method to balance product quality and cost.

Annex 2 Examination and improvement of the quality level

1 Scope This Annex specifies the methods of examining and improving the quality level in connection with product quality specific values.

2 Definitions and symbols For the purposes of this Annex, in addition to the definitions and symbols given in the body of this Standard and Annex 1, the following definitions and symbols apply:

- (1) **dynamic characteristic** A characteristic that can evaluate variation based on the relationship of the input signal and the output characteristic in order to realize an output of a system. (In contrast, smaller-is-better, nominal-is-best and larger-is-better characteristics are sometimes called static characteristics.) For example, the output of measuring device, the output of sensors or product dimensions belong to dynamic types.
- (2) **signal factor** An input used to change the output of a system.
- (3) **noise factor** The conditions cited to represent the causes of variation in a system.
- (4) **SN ratio (η)** The ratio of the power of signal to the power of noise in dynamic characteristics. The power of signal is the magnitude of signal factor effect, and the power of noise is the magnitude of noise factor effect. In the case of non-dynamic characteristics, an SN ratio can be calculated for convenience by using the effect of the mean and the power of noise.
- (5) **current loss (L_1)** The loss estimated from current quality level.
- (6) **maximum allowable loss (L_2)** The loss estimated from a product whose characteristic is equal to the specification limit.

3 Examination of quality level Compare the designed value of Δ and current mean squared error V_T . The quality level is examined using the following procedures:

Procedure 1 Calculate the mean squared error V_T of a product under current condition from y_i ($i = 1, \dots, n$) and the nominal value m_0 using the following equations:

- (1) **Smaller-is-better characteristic**

$$V_T = \frac{1}{n} (y_1^2 + y_2^2 + \dots + y_n^2)$$

- (2) **Nominal-is-best characteristic**

$$V_T = \frac{1}{n} \{ (y_1 - m_0)^2 + (y_2 - m_0)^2 + \dots + (y_n - m_0)^2 \}$$

- (3) **Larger-is-better characteristic**

$$V_T = \frac{1}{n} \left(\frac{1}{y_1^2} + \frac{1}{y_2^2} + \dots + \frac{1}{y_n^2} \right)$$