
**High velocity oxygen fuel (HVOF)
cermet coatings for metallurgical
roll components — Guidance with
requirements**

*Revêtements de cermet par pulvérisation oxycombustible à grande
vitesse (HVOF) pour les composants de rouleaux métallurgiques —
Recommandations et exigences*

STANDARDSISO.COM : Click to view the full PDF of ISO 4289:2023



STANDARDSISO.COM : Click to view the full PDF of ISO 4289:2023



COPYRIGHT PROTECTED DOCUMENT

© ISO 2023

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

	Page
Foreword.....	iv
Introduction.....	v
1 Scope.....	1
2 Normative references.....	1
3 Terms and definitions.....	1
4 Recommended HVOF cermet coating materials for various metallurgical rollers.....	2
5 Preparation of HVOF cermet coatings for various metallurgical rollers.....	2
5.1 Pre-treatment of various metallurgical components.....	2
5.2 HVOF spraying.....	3
5.3 Post-process of HVOF sprayed coatings.....	3
6 Coating quality and performance evaluation.....	3
6.1 General.....	3
6.2 Coating quality.....	3
6.3 Performance evaluation of coatings.....	4
6.3.1 Thickness.....	4
6.3.2 Surface roughness.....	5
6.3.3 Bonding strength.....	5
6.3.4 Porosity.....	5
6.3.5 Microhardness.....	5
6.3.6 Friction and wear test.....	6
6.4 Sealing treatment of coatings.....	9
Bibliography.....	11

STANDARDSISO.COM : Click to view the full PDF of ISO 4289:2023

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 107, *Metallic and other inorganic coatings*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Metallurgical rollers are the key components used in the steel industry. However, rollers considered to be consumables with premature failure often occurring on the roller surface. The surface quality of rollers determines the quality of products and also affects production efficiency. High velocity oxygen fuel (HVOF), as an environmentally friendly technology, has become a promising technology for improving the surface quality of rollers, thus extending the service life. Up until now, HVOF cermet coatings (e.g. tungsten carbide based, chromium carbide based) have been widely used in various rollers (e.g. hot dip galvanized line, continuous annealing furnace) in the metallurgical industry around the world. In the process of metallurgical production, the specific coating is determined by the working conditions of the rollers used.

This document aims to promote the technical progress of the industry.

STANDARDSISO.COM : Click to view the full PDF of ISO 4289:2023

[STANDARDSISO.COM](https://standardsiso.com) : Click to view the full PDF of ISO 4289:2023

High velocity oxygen fuel (HVOF) cermet coatings for metallurgical roll components — Guidance with requirements

1 Scope

This document specifies recommendations and requirements for the selection of coating materials, the pre-treatment of rollers, the preparation and post-treatment of the coatings, as well as the quality and performance evaluation of high velocity oxygen fuel (HVOF) cermet coatings used on metallurgical roll components.

This document is applicable to four metallurgical rollers: pot inner roller (sink/stabilizing roller) of continuous galvanized line (CGL), cold rolling process roller, hot-rolled straightening roller and furnace roller.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14921, *Thermal spraying — Procedures for the application of thermally sprayed coatings for engineering components*

ISO 14916, *Thermal spraying — Determination of tensile adhesive strength*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

pot inner roller (sink/stabilizing roller) of continuous galvanized line

pot inner roller (sink/stabilizing roller) of CGL

roller that ensures the stable flow of the steel strip into the zinc pot

3.2

cold rolling process roller

main working part of the sheet mill, which determines the quality of the rolled material and the production efficiency of the mill

3.3

hot-rolled straightening roller

core part of the hot rolling strip mill, which is composed of six rollers

3.4 furnace roller

key part of a continuous annealing furnace in the continuous strip production line

Note 1 to entry: The quality of the furnace roller directly affects the surface quality of strip steel.

4 Recommended HVOF cermet coating materials for various metallurgical rollers

The appropriate coatings for the pot inner roller (sink/stabilizing roller) of CGL, cold rolling process roller, hot-rolled straightening roller, and furnace rollers should be as given in [Table 1](#). Generally, the damages to rollers include corrosion, wear, high-temperature oxidation, etc. The recommendation of coatings is determined by the failure of the rollers, as shown in [Table 1](#).

Table 1 — Failures and recommended coating materials for various metallurgical rollers

Rollers	Failures				Example of recommended coatings	Powder manufacturing methods	Particle size
	Corrosion	Wear	Oxidation	Accumulation of tumours			
Pot inner roller (sink/stabilizing roller) of CGL	√	√	/	√	WC-xCo	Agglomerated and sintered	-45 μm +15 μm
Cold rolling process roller	√	√	/	/	WC-xM(NiCr, Co)		
Hot-rolled straightening roller	/	√	/	/	WC-xCo		
Furnace rollers (500 °C to 700 °C)	/	√	√	√	Cr ₃ C ₂ -xNiCr		
Furnace rollers (≥800 °C)	/	√	√	√	MCrAlY(M = Ni/Co/NiCo) + oxides, carbides or borides		
Key √ : possessing this failure form / : there is no such failure form x : mass fraction of the metallic phase, which should be controlled within a mass fraction of 10 % to 50 %							

5 Preparation of HVOF cermet coatings for various metallurgical rollers

5.1 Pre-treatment of various metallurgical components

The surface of the rollers should be inspected and reviewed to ensure their suitability before spraying. These procedures should be followed for the pre-treatment and surface preparation of the metallurgical components:

- a) It is necessary to remove the impurities generated during the production process to obtain a clean surface. For the pot inner roller (sink/stabilizing roller) of CGL, the residuary zinc on the surface should be removed by dilute acid solution, using the following steps:
 - 1) Preparation of dilute acid solution: The concentration of sulphuric acid mass percentage should be controlled within 3 % to 7 %.
 - 2) Immersion: The dipping time of zinc removal treatment should be controlled within 6 h to 72 h.

- 3) **Cleaning:** The sinking/stabilizing rollers together with the special lifting frame should be cleaned by soaking and rinsing.
- 4) **Airing:** After soaking and rinsing, the workpieces should be together with the special lifting frame on the fixed pit position to dry.
- b) The roller surface should be inspected to ensure that there are no defects or cracks on the surface. If shrinkage cavities, pores and sand holes are present, their size should be smaller than 0,5 mm. If there are cracks or defects with a size larger than 0,5 mm, partial substrate from the roller surface should be carried out by a carbide tool head. Pits larger than 3 mm in diameter shall not be present on the roller surface after processing. The surface roughness should be lower than 3,2 μm .
- c) Prior to spraying, grinding and polishing should be carried out to obtain a surface of which the roughness is lower than 0,8 μm . To enhance the adhesion of coatings to rollers, sandblasting is employed to roughen the working surface.

5.2 HVOF spraying

HVOF spraying shall be operated in accordance with ISO 14921.

5.3 Post-process of HVOF sprayed coatings

There should be a post-process inspection and operation of HVOF sprayed coatings, including sealing pores, heat treatment and dynamic/static balance.

The inspection of the coatings should be carried out after spraying via measurement of thickness, roughness, microhardness and bonding strength.

Thermal spraying sink/stabilizing rollers and furnace rollers should be sealed. Once spraying is finished, seal the pores as soon as possible. For sealing, a range of different sealants and procedures are available and the supplier's instructions should be followed.

6 Coating quality and performance evaluation

6.1 General

The performance of the coating, such as thickness, roughness, porosity, hardness, etc., can influence wear resistance, corrosion resistance and stability, thereby affecting its service life. Therefore, it is necessary to provide the coating quality (see 6.2) and an evaluation of its performance (see 6.3).

6.2 Coating quality

Recommended performance indicators for various metallurgical roller components is given in [Table 2](#).

Table 2 — Recommended performance indicators for various metallurgical roller components

	Performance indicators					
	Thickness μm	Bonding strength MPa	Surface roughness R_{pk}	Porosity	Micro-hardness $H_{V0,3}$	Friction coefficient
Pot inner roller (sink/stabilizing roller) of CGL	≈ 150 to 200	≥ 70	≤ 30 % (decreasing rate after 360 h operation)	≤ 1 % for as-sprayed; $\leq 0,3$ % after sealing	1 050 to 1 150	/
Key						
/ : no performance requirement						

Table 2 (continued)

	Performance indicators					
	Thickness μm	Bonding strength MPa	Surface roughness R_{pk}	Porosity	Micro-hardness $H_{V0,3}$	Friction coefficient
Cold rolling process roller	≈ 180 to 200	>65	3,6 μm ± 0,1 μm	/	750 to 1 100	0,23 ± 0,02
Hot-rolled straightening roller	≥180	>70	<0,8 μm	<1 %	1 000 to 1 300	/
Furnace rollers (500 °C to 700 °C)	100 to 200	>65	Not constant value, determined by the specific work position	<1 %	775 to 950	/
Furnace rollers (≥800 °C)	100 to 200	>50	Not constant value, determined by the specific work position	<5 %	600 to 850	/
Key / : no performance requirement						

6.3 Performance evaluation of coatings

6.3.1 Thickness

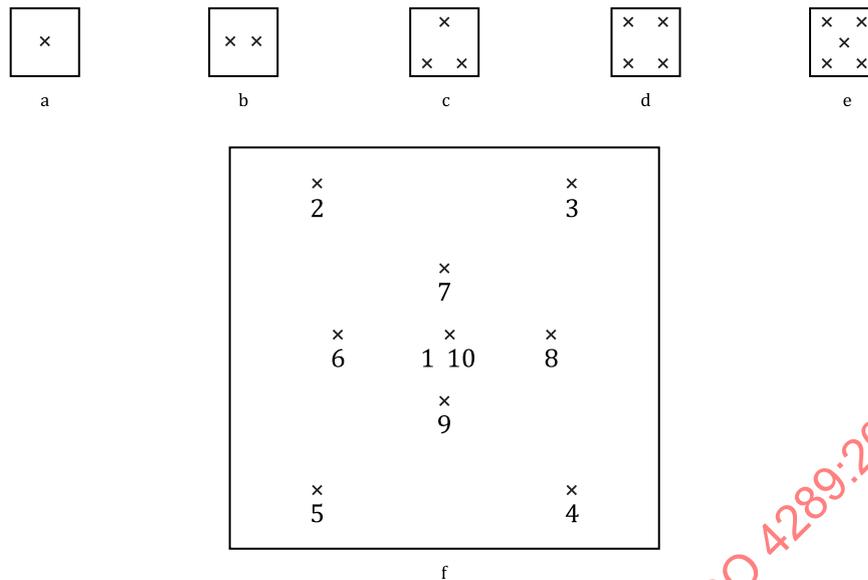
Although there are many methods for measuring the thickness of the coating, for the HVOF cermet coatings of rollers, two common and accurate measurement methods are given, as follows:

- a) Destructive test method: In order to test the thickness of the coating accurately, the specimens should be cut, cleaned, mounted and polished. A scanning electron microscope (SEM) is used to measure the coating thickness following the steps in ISO 9220.
- b) Non-destructive test method: The in situ coating thickness can be measured in the production line through non-destructive methods. A magnetic sample is fixed next to the roller being sprayed and the coating thickness is determined by measuring the thickness of the magnetic sample with an eddy current thickness gauge when the coating process is finished.

The steps for in-line testing of the coating thickness are as follows:

- The specimens used for thickness test should be magnetic and the distance to the spray gun should be consistent with the roller.
- Prepare three samples cooled to room temperature.
- Measure the thickness by the non-destructive method. The number of points measured for each specimen depends on its size. The detailed requirements are as follows:
 - For samples with a main surface less than 1 cm², 1 to 3 distributed measurements shall be made.
 - For samples with a main surface greater than 1 cm² and less than 1 m², 3 to 5 distributed measurements shall be made.
 - For samples with a main surface greater than 1 m², 9 points and 10 distributed measurements shall be made. The first and tenth measurement points shall coincide.

The distribution of measurement points is shown in [Figure 1](#).

**Key**

- x Distributed measurements.
- a Single measurement.
- b Two distributed measurements.
- c Three distributed measurements.
- d Four distributed measurements.
- e Five distributed measurements.
- f Nine distributed measurements.

The numbering 1 to 10 indicates the order and number of measurements.

Figure 1 — Distribution map of measurement points

6.3.2 Surface roughness

When measured according to ISO 8503-4, the R_a value (i.e. the surface roughness) can be directly read by measuring the contour information of the surface with a stylus electric profilometer.

6.3.3 Bonding strength

The bonding strength of the coating shall be measured in accordance with ISO 14916.

6.3.4 Porosity

The evaluation of the porosity of coatings should follow the steps given in ISO/TR 26946.

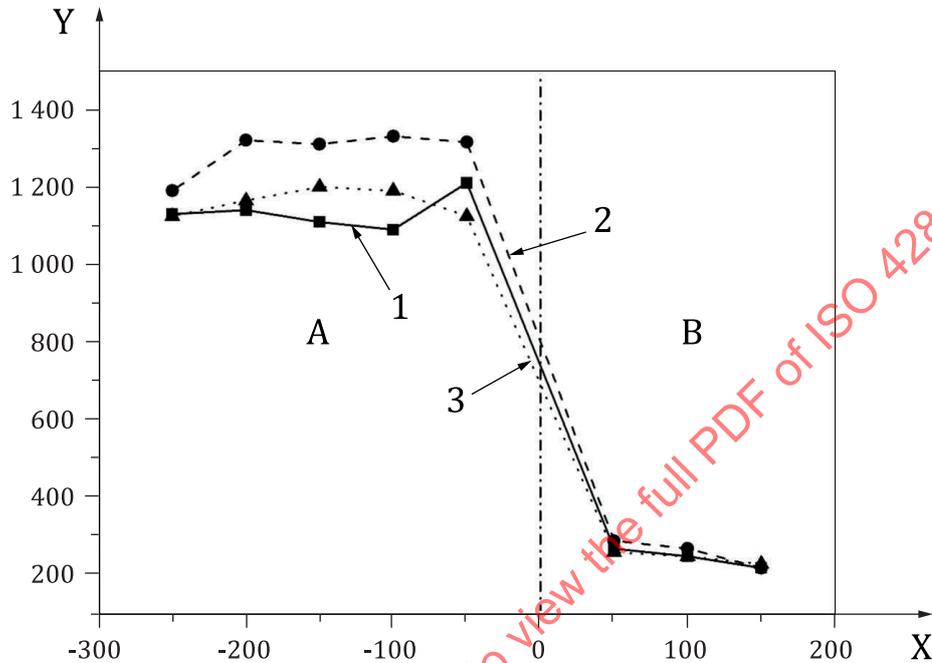
6.3.5 Microhardness

Based on ISO 6507-1 and ISO 4545-1, there are two types of microhardness indenters: a narrow rhombus-shaped diamond indenter for the Knoop and a square base pyramid-shaped diamond indenter for the Vickers. Microhardness values of the cermet coatings are significantly affected by surface roughness and defects. Test forces should be chosen that result in indentations with diagonals greater than 20 μm .

For HVOF cermet coatings, the following information applies:

- a) Vickers indentation makes a deeper impression than the Knoop indentation under the same load. Therefore, the Vickers microhardness test is more suitable for cermet coatings.

b) Before microhardness testing, the specimens should be polished. The surface roughness should be less than 0,1 μm. The microhardness of coatings can be measured on both surface and cross-section with a load of more than 3 N and a dwelling time of 10 s using a microhardness tester. For surface hardness, more than 10 points should be measured to ensure the accuracy of the data. For the cross-section hardness of HVOF-sprayed coatings, three different lines from the substrate to the top work layer should be tested on the cross-sectional surface. As shown in Figure 2, the data near the substrate and surface are not very stable. Test data should be selected in the region which is more than 20 μm away from the substrate and the surface.



Key

X	hardness, HV _{0,3}	1	WC-12Co
Y	distance, μm	2	WC-10Co-4Cr
A	coating	3	WC-12Co-NiCrBSi
B	substrate		

Figure 2 — Diagram of microhardness evolution with the distance to substrate

6.3.6 Friction and wear test

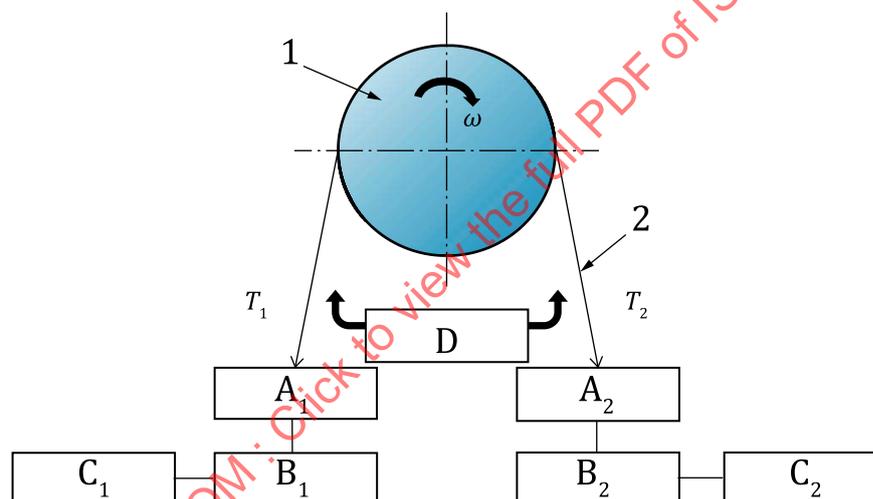
Friction and wear properties of HVOF-sprayed coatings decide their performance in different metallurgical components. According to ISO 20808, the ball-on-disk (BOD) test is applied to characterize their tribological properties. Since surface roughness has a strong effect on the tribological behaviour of coatings, the coating specimens should be polished before the test.

For HVOF coatings, the following information applies:

- a) **Wear counterparts:** The wear counterparts should be considered depending on working conditions and should possess enough strength to ensure normal progress of friction and wear. Considering the actual working conditions where the steel plate and rollers are in direct contact, the wear counterparts should be steel balls and the diameter of the sphere should be in the range of 5 mm to 8 mm.
- b) **Applied temperature:** The applied temperature shall be selected in accordance with the specific working conditions of rollers. The temperatures should be:
 - 1) 460 °C to 480 °C for pot inner rollers (sink/stabilizing roller) of CGL;

- 2) 20 °C to 200 °C for cold rolling process rollers;
 - 3) room temperature for hot-rolled straightening rollers;
 - 4) 500 °C to 1 000 °C for furnace rollers.
- c) Applied load: 10 N to 30 N, depending on the force applied to the rollers.
 - d) Sliding speed: 0,05 m/s to 0,3 m/s, depending on the rotation speed of the rollers, and the diameter of the sliding circle should be more than 3 mm or the amplitude of reciprocating motion is greater than 2,5 mm.
 - e) Sliding distance: 300 m to 800 m.
 - f) For cold rolling process roll, there is a static friction between the steel plate and the roller surface in cases of no slippage, but it is difficult to test the static friction coefficient through a working condition simulation. Therefore, the anti-skid property of the coating is characterized by roughly measuring the sliding friction coefficient between the protective coating and the steel plate.

The test device for sliding friction coefficient is shown in [Figure 3](#).



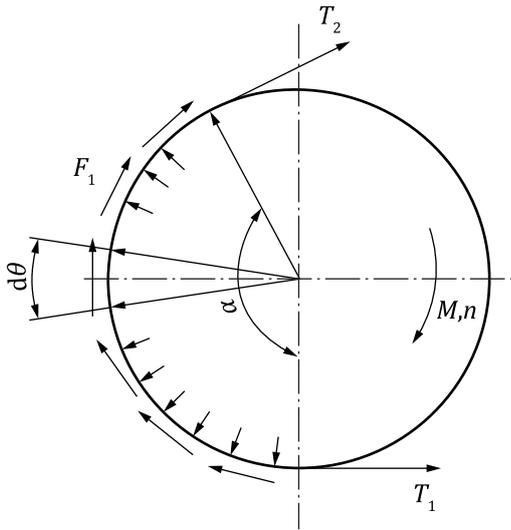
Key

1	testing roller	B ₁	wrap angle detection point at T ₁ direction
2	strip steel	B ₂	wrap angle detection point at T ₂ direction
ω	angular velocity	C ₁	Data collection at T ₁ direction
A ₁	tension adjustment at T ₁ direction	C ₂	Data collection at T ₂ direction
A ₂	tension adjustment at T ₂ direction	D	wrap angle adjustment θ

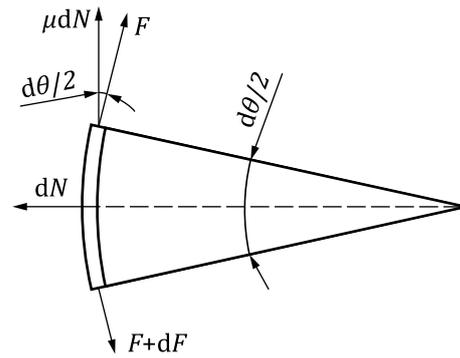
Figure 3 — Test equipment for sliding friction coefficient between coating and steel plate

The sliding friction coefficient between the protective coating and the steel plate is measured as follows:

- As shown in [Figure 4 a\)](#), when the strip has a slip tendency, the friction reaches its limit value. At this time, the tension of the transmission belt strip is also at the maximum. Next, the calculation method of the maximum tension of the transmission is analysed.
- The direction of friction force of roll to strip steel is the same as the direction of T₂, and the friction force reaches the maximum value. If the influence of centrifugal force is omitted when moving along the arc, the strip steel with a small length is taken as a separator, see [Figure 4 b\)](#).



a) Force analysis of strip steel



b) Element tension analysis

Key

F	frictional force, N	M	torque required by the roller, N · m
α	actual wrap angle between strip and roller, rad	N	motor power, kW
θ	geometric wrap angle between strip and roller, rad	μ	friction coefficient
T_1	tension force at counter clockwise direction, N	n	rotate speed of roller, r/min
T_2	tension force at clockwise direction, N		

Figure 4 — Tension decomposition of strip steel

The equilibrium formula of force is shown by [Formula \(1\)](#):

$$\left. \begin{aligned} dN &= F \sin \frac{d\theta}{2} + (F + dF) \sin \frac{d\theta}{2} \\ \mu dN + F \cos \frac{d\theta}{2} &= (F + dF) \cos \frac{d\theta}{2} \end{aligned} \right\} \quad (1)$$

where

- N is the motor power, in kW;
- θ is the geometric wrap angle between strip and roller, in rad;
- F is the friction force, in N;
- μ is the friction coefficient.

As $d\theta$ is very small, select $\sin \frac{d\theta}{2} = \frac{d\theta}{2}$ and omit the quadratic different $dF \cdot \sin \frac{d\theta}{2}$, $\cos \frac{d\theta}{2} = 1$.

[Formula \(1\)](#) is converted to [Formula \(2\)](#):

$$\left. \begin{aligned} dN &= F d\theta \\ \mu dN &= dF \end{aligned} \right\} \frac{dF}{F} = \mu d\theta \quad (2)$$

where

- N is the motor power, in kW;