Hot Strip Mill Model (HSMM) ver. 1.0

Product Help

Project TE01020197 “Centre for Applied Cybernetics 3”,
Competence Centre Program TA CR

This product was developed within work package WP11 of the project TE01020197 “Centre for Applied Cybernetics 3” supported by the Technology Agency of the Czech Republic under the Competence Centre Program. The development of the software was achieved by the cooperation between Applied Cybernetics Laboratory at Faculty of Mechanical Engineering of Czech Technical University in Prague and PIKE Automation, Ltd.

HSMM (ver. 1.0) is the software which resulted from the cooperation with PIKE Automation, Ltd., and is implemented in language C#. This software enables the user to schedule the strip rolling on finishing mills, including roll force and roll gap evaluations. This software also allows the user for metallurgy influence treatment and strip temperature prediction. In addition, the metallurgical property dependence on the temperature is included. In summary, four essential types of rolling steels are considered for scheduling the strip rolling and the number of finishing mills can be set from 4 to 7. To distinguish among large variety of steel grades the HSMM software gives the user the possibility to specify the chemical composition, too.

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1 Main window – Hot Strip Mill Parameters

Main window contains geometry and metallurgy panels where the temperature model panel is incorporated into the metallurgy panel. Once all the required parameters of

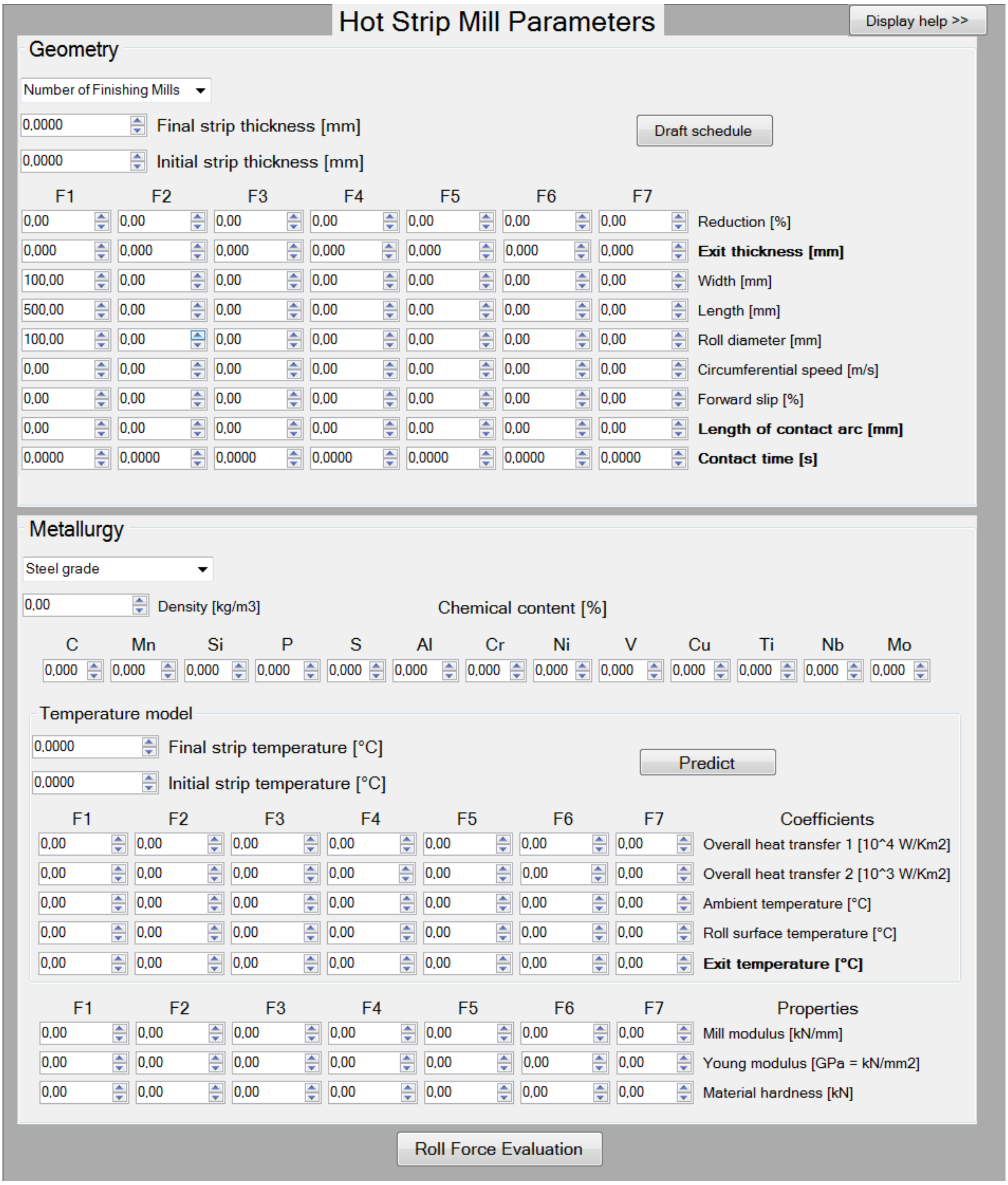

Fig. 1.1 Main Window – Hot Strip Mill Parameters

corresponding panels are given then these parameters are verified and unspecified ones are evaluated by clicking the button of the corresponding panels (“Draft schedule” and “Predict” buttons) in Fig. 1.1. After clicking the button “Roll Force Evaluation” the new window with Roll force model parameters is open only if both buttons, “Draft schedule” and “Predict”, are previously clicked without any error message. Generally, the variables tagged by the labels in **bold face** are found out by the HSMM ver. 1.0 if the remaining variables (constants) are given. The product help of the HSMM ver. 1.0 can be launched by clicking the button “Display help” that is displayed on the right-hand side of the main window, for more details on the help see Chapter 4.

1.1 Geometry parameters panel

The geometry panel comprises material reduction, exit strip thickness, strip width and length, roll diameter, circumferential speed, forward slip, length of contact arc, contact time. First of all the number of finishing mills and the final strip thickness have to be given. In case of initial strip thickness, which occurs in the entry of F1 (the first finishing mill), there are two possibilities of its function. Either the initial strip thickness is fixed to a nonzero value and then the corresponding material reductions are computed, including the exit thicknesses, or the initial strip thickness is zero-filled and then this initial strip thickness is found out with respect to the scheduled material reductions. To evaluate any change in geometry parameter the button “Draft schedule” is to be clicked.

To facilitate the geometrical parameter setting there is the possibility to completely zero-fill all entries of material reduction, strip width, strip length, circumferential speed, and forward slip over the whole of the finishing mills by clicking the corresponding label on the Main window in Fig. 1.1.

1.1.1 Specification of the number of finishing mills

The number of finishing mills can be selected from 4 to 7. In case no number of finishing mills is selected the parameter verification and evaluation fail.

1.1.2 Specification of the final strip thickness

The final strip thickness is on the exit of the last finishing mill, given by the selected number of finishing mills. The last finishing mill can be one of the following mills, namely F4, F5, F6 and F7. The final strip thickness must be specified by the user and is between 0 and 10 mm. Generally, the final strip thickness must be less than the initial strip thickness.

1.1.3 Specification of the initial strip thickness

The initial strip thickness is on the entry of F1 (the first finishing mill). The initial strip thickness is fixed to the value between 0 and 100 mm. In case the initial strip thickness is set to nonzero value the evaluated material reductions can also result negative. Therefore proper initial strip thickness has to be specified or let the initial strip thickness be zero-filled and then this initial strip thickness is evaluated with respect to the scheduled material reductions, for more details on reduction evaluation see material reductions.

1.1.4 Specification of the material reduction

The material reduction is fixed to the value between 0 and 100 %. Generally, the material reductions should be positive and should be descending in their values over all finishing mills. However, due to improper setting of the initial strip thickness the material reductions can result not only in ascending values across all the finishing mills but also in negative values. To overcome these errors the user should apply one or more of the following precautions:

1.) Change the number of finishing mills.

2.) Increase/decrease the initial strip thickness.

3.) Set greater/lower values of the material reductions.

To take these precautions effect the button “Draft schedule” is to be clicked. For more details on error solutions see Error messages with ID: MW05 and MW06.

1.1.5 Specification of the exit strip thickness

The exit strip thickness must result in nonzero value and must be in its value descending consecutively from the first to the last finishing mill. In case the previous statements are not satisfied, please, follow the instructions of the Error messages. The exit strip thickness is typed in **bold face** because this variable is found out by the HSMM ver. 1.0, see Fig. 1.1.

1.1.6 Specification of the strip width

The strip width is commonly between 600 and 1 500 mm. From computational viewpoint the width range is expected from 0 to 2 500 mm. The strip width on the entry of F1 (the first finishing mill) is automatically set to nonzero value by the HSMM ver. 1.0 which, changed by the user to the true value, is copied on following finishing mills only if the width on the following mills is previously set to zero. This is because the finishing mills widen the strip very slightly. In case the individual strip widths should be applied it is sufficient to set nonzero strip widths behind F1.

1.1.7 Specification of the strip length

The strip length is considered as the distance between two finishing mills in mm. Then the strip length is commonly between 2 500 and 7 000 mm. From computational viewpoint the length range is expected from 0 to 10 000 mm. The strip length given by the distance between adjacent finishing mills, namely F1 and F2, is automatically set to nonzero value by the HSMM ver. 1.0 which, changed by the user to the true value, is copied on following finishing mills only if the length among the following mills is previously set to zero. In case the individual strip lengths should be applied it is sufficient to set nonzero strip lengths behind F2. So many strip lengths are specified as many finishing mills less than one are.

1.1.8 Specification of the roll diameter

The roll diameter must be given as positive and in descending/not increasing values consecutively throughout the finishing mills. Usually the roll diameter is between 500 and 1 000 mm. From computational viewpoint the roll diameter range is expected from 0 to 2 500 mm. The roll diameter is gradually flattened by rolling and this fact brings about an increase of the material hardness and thus an increase of the roll force. Unfortunately, there is not reliable computational method for the determination of the flattened roll diameter, yet. In case the roll radius results less than the length of contact arc, a scheduling error occurred. Hence, please, follow the instructions of the Error messages with ID: MW19.

1.1.9 Specification of the circumferential speed and forward slip

The circumferential speed of work roll is specified in m/s and must result in not decreasing values consecutively throughout the finishing mills. If the circumferential speed of the work roll on F1 (the first finishing mill) is properly estimated and at the same time the forward slip of corresponding work rolls is given then the circumferential speeds behind F1 are evaluated. These evaluations are again done by clicking the button “Draft schedule”. Reversely, if the forward slip of work roll on F1 (the first finishing mill) is properly estimated (simultaneously the forward slips on remaining finishing mills are set to zero) and at the same time the circumferential speed of corresponding work rolls is given then the forward slips behind F1 are evaluated. In summary, the user can estimate either the circumferential speeds or the forward slips. Since the forward slip of work rolls on corresponding finishing mills is approximately between 0 and 10 % and there is large variability of the circumferential speed over the whole of the finishing mills the user should prefer the circumferential speed estimation over the forward slip estimation. Thus, it is very difficult to specify directly proper circumferential speed. The circumferential speed is meaningful to consider between 0 and 10 m/s but from computational viewpoint the circumferential speed range is suggested from 0 to 20 m/s.

1.1.10 Specification of the length of contact arc

The length of contact arc is straightforwardly computed from the knowledge of the roll diameter, adjacent exit thicknesses and reduction. Generally the length of contact arc must be descending over the whole of the finishing mills. In case the previous statement is not satisfied, please, follow the instructions of the Error messages particularly the error with ID MW18. The length of contact arc is typed in **bold face** because this variable is found out by the HSMM ver. 1.0, see Fig. 1.1.

1.1.11 Specification of the contact time

The contact time is straightforwardly computed from the knowledge of the length of contact arc, circumferential speed, forward slip and adjacent exit thicknesses. Since the circumferential speed is in the denominator of the relation for the contact time the circumferential speed is tested on nonzero value. In case of its (nearly) zero value an error is displayed and new scheduling must be proceeded, mainly the circumferential speed or forward slip estimation. Please, follow the instructions of the Error messages. The contact time is typed in **bold face** because this variable is evaluated by the HSMM ver. 1.0, see Fig. 1.1. In fact, the reciprocal value of the contact time is the decisive value for the strain rate computation using linear regression model.

1.2 Metallurgy parameters panel

The metallurgy panel comprises steel grade, density, chemical content, mill modulus, Young modulus, material hardness. In addition, the metallurgy panel is equipped with the built-in temperature model panel where there are final strip temperature, initial strip temperature, overall heat transfer coefficient 1 and 2, ambient temperature, roll surface temperature and strip exit temperature. The metallurgical properties can be evaluated only when the strip exit temperatures of corresponding finishing mills are determined. The temperature evaluation is proceeded by clicking the button “Predict”. The number of exit temperatures being determined is inherited from the geometry panel through the number of finishing mills.

1.2.1 Specification of the steel grade

The steel grade is distinguished by four essential types, namely mild steel, microalloy steel, carbon steel and stainless steel. In case no steel grade is selected the parameter verification and evaluation fail. To provide a finer division of steel grades the chemical content can be specified.

1.2.2 Specification of the density

The steel density is considered as a fixed value in kg/m^3. Since the steel density depends on the chemical content it is necessary first to know how the steel is alloyed. Generally, the steel density is between 7 400 and 8 000 kg/m^3. Typically, its value is 7 850 kg/m^3.

1.2.3 Specification of the chemical content

The chemical content [%] is composed of following elements, C(carbon), Mn(manganese), Si(silicon), P(phosphorus), S(sulfur), Al(aluminum), Cr(chromium), Ni(nickel), V(vanadium), Cu(copper), Ti(titanium), Nb(niobium) and Mo(molybdenum). All the element contents are supposed to be specified as weight contents.

1.2.4 Specification of the mill modulus

The mill modulus is the property specified by the rolling mill producer. The mill modulus is required by the software in kN/mm and is increasing with rising strip temperature. If the mill modulus is not specified then the roll gap cannot be computed. The relation for the roll gap computation is introduced in the section Specification of the roll gap. given by the following relation

1.2.5 Specification of the Young modulus

The Young modulus is the metallurgical property of the rolled steel. The Young modulus is required in kN/mm^2 and is increasing with rising strip temperature. If the Young modulus is not specified then the flattened roll diameter cannot be computed.

1.2.6 Specification of the material hardness

The material hardness is the metallurgical property of the rolled steel. The material hardness is required in kN and increases with the roll flattening. Hence without the knowledge of the Young modulus the material hardness cannot be evaluated precisely.

1.2.7 Built-in temperature model parameters panel

The temperature model comprises final strip temperature, initial strip temperature, overall heat transfer coefficient 1 and 2, ambient temperature, roll surface temperature and exit strip temperature. Also there is a property, called specific heat and not displayed by the HSMM ver. 1.0, which is internally determined for the purpose of exit temperature prediction. However the specific heat can be determined after the corresponding exit strip temperatures are known. Hence instead of the exit temperature prediction model is applied the backward exit temperature model computing the exit temperatures in the order from the final strip temperature to the initial strip temperature. Generally, the metallurgical properties can be evaluated only when the exit strip temperature of corresponding finishing mills is determined. The temperature evaluation is proceeded by clicking the button “Predict”. The number of exit temperatures being determined is inherited from the geometry panel through the number of finishing mills.

The specific heat, heat transfer coefficient and steel grade specification comply with the European standard EN 1993-1-2:2005[1] and the temperature prediction model is verified and validated according to the ASME standard ASME V&V 20-2009[2].

1.2.7.1 Specification of the final strip temperature

The final strip temperature is technologically assigned target for the hot strip mill rolling. The final strip temperature is on the exit of the last finishing mill, given by the selected number of finishing mills. The last finishing mill can be one of the following mills, namely F4, F5, F6 and F7. The final strip temperature must be specified by the user and is between 0 and 1 000 °C. Generally, the final strip temperature must be less than the initial strip temperature.

1.2.7.2 Specification of the initial strip temperature

The initial strip temperature is on the entry of F1 (the first finishing mill). The initial strip temperature is fixed to the value between 0 and 1 500 °C. In case the initial strip temperature

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[1] (3)
[2] (4)

is set to nonzero value the exit strip temperatures are determined by an interpolation between the initial and final strip temperatures. Moreover, proper initial strip temperature is to be set, i.e. greater than the final strip temperature. Reversely, if the initial strip temperature is zero then the exit strip temperature of corresponding finishing mills is found using backward temperature model if overall heat transfer coefficient 1 and 2, ambient temperature and roll surface temperature are previously specified.

1.2.7.3 Specification of the overall heat transfer coefficient 1

The overall heat transfer coefficient 1 specifies the overall heat transfer between the surface of hot strip and surface of the work roll. The overall heat transfer coefficient 1 is suggested in W/Km^2 and given by the order 10^4. Hence only coefficients divided by 10^4 are applicable for their settings. Finally, the roll surface temperature must be given to evaluate the overall heat transfer through the length of the contact arc and the strip width.

1.2.7.4 Specification of the overall heat transfer coefficient 2

The overall heat transfer coefficient 2 specifies the overall heat transfer between two finishing mills. The distance between them is given by the strip length. The overall heat transfer coefficient 2 is suggested in W/Km^2 and given by the order 10^3. Hence only coefficients divided by 10^3 are applicable for their settings. The overall heat transfer coefficient 2 is an average of all the coefficients related to the intensity of water and/or air cooling. Finally, the ambient temperature must be measured or estimated to evaluate the overall heat transfer between the hot strip and its ambient.

1.2.7.5 Specification of the ambient temperature

The ambient temperature is the temperature of surrounding medium of the hot strip. The ambient temperature can be either near 100 °C or much greater than 100 °C. The former corresponds to the water cooling while the latter to the air cooling.

1.2.7.6 Specification of the roll surface temperature

The roll surface temperature can quite exceed 500 °C mainly on the first finishing mills but usually its value is less than 500 °C. As regards the temperature of the kernel of the work roll it is approximately 100 °C due to work roll water cooling.

1.2.7.7 Specification of the exit strip temperature

The exit strip temperatures result from either the interpolation model or the prediction model application. The former is the case when the temperature distribution through the finishing mills is interpolated from the specified initial strip temperature to the assigned final strip temperature. The latter case belongs to the exit strip temperature computation from the backward temperature model which is derived from the temperature prediction model. Originally, the temperature prediction model provides one step ahead prediction, i.e. the prediction from the temperature on one to the temperature on another finishing mill. Because the temperature prediction requires the knowledge of the specific heat that depends on the predicted exit temperatures the prediction temperature model is translated to the backward temperature model calculating the exit temperatures recurrently, in other words from the final to initial strip temperature. If the exit strip temperatures do not result descending in their values consecutively from the initial to final strip temperature then a computation error occurred, for more details see Error messages. The exit strip temperature is typed in **bold face** because this variable is found out by the HSMM ver. 1.0, see Fig. 1.1.

2 New window – Roll Force Model Parameters

New window is launched after clicking the button “Roll Force Evaluation” on the Main window - Hot Strip Mill Parameters. However, this click should follow only when no error messages are present after clicking both buttons “Draft schedule” and “Predict”, respectively, on the Main window. The new window contains three panels, namely Hot yield strength panel, Roll force panel and Roll gap panel. First, the hot yield strength is to be evaluated by clicking the button “Compute” and then the roll force can be computed by clicking the button “Evaluate”. Similarly, the roll gap can be shown by clicking another button “Evaluate”. Generally, the variables tagged by the labels in **bold face** are found out by the HSMM ver. 1.0 if the remaining variables (constants) are given.

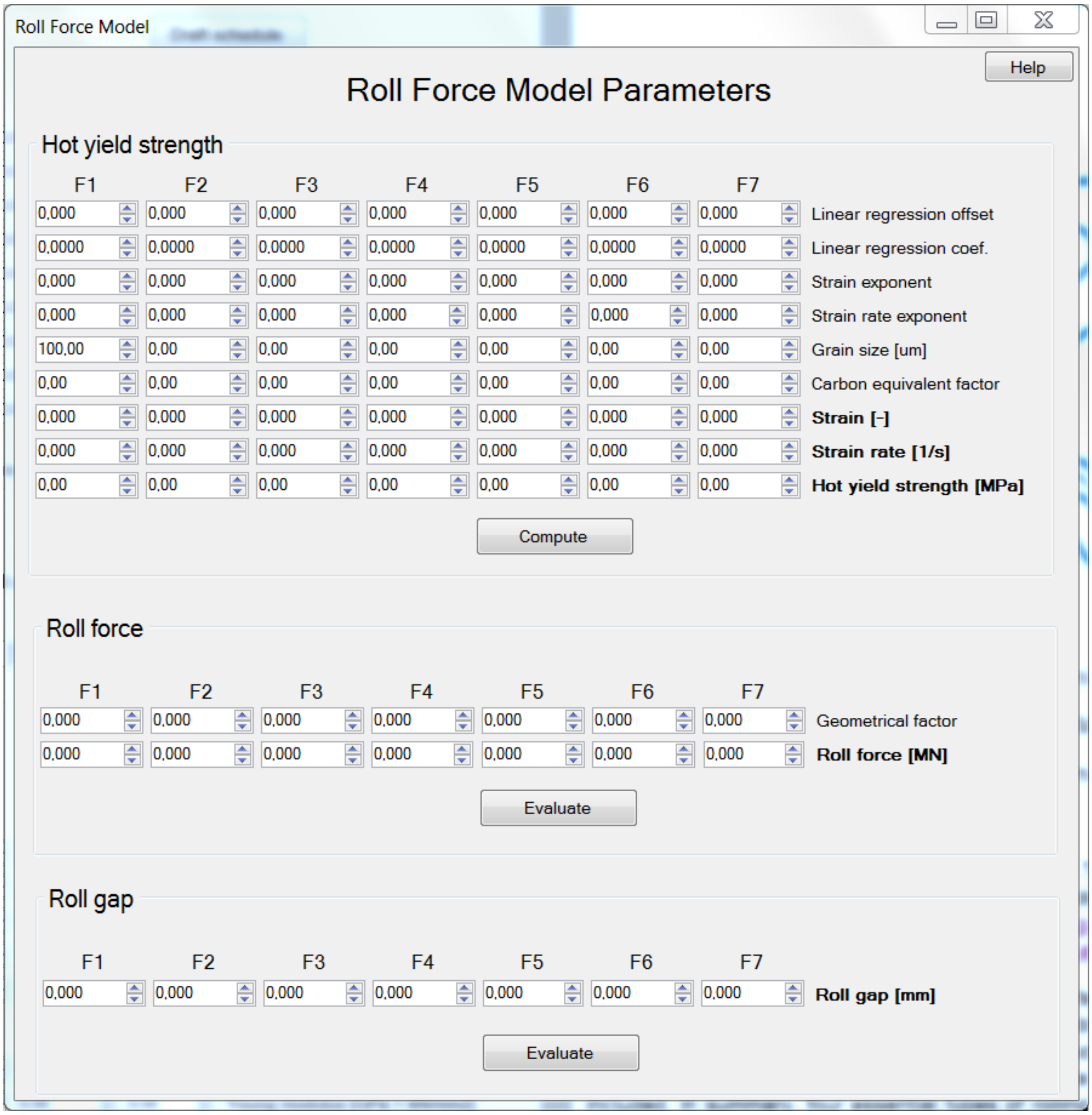

Fig. 2.1 New Window – Roll Force Model Parameters

2.1 Hot yield strength parameters panel

The hot yield strength panel comprises the hot yield strength, strain and strain rate as the found out variables that are typed in **bold face**, see Fig. 2.1. The remaining parameters (constants) are offset of linear regression, linear regression coefficient, strain exponent, strain rate exponent, grain size and carbon equivalent factor. To find out the variables typed in bold face many parameters are inherited from the Main window, first of all the number of finishing mills and the steel grade. To evaluate any change in parameter(s) of the hot yield strength panel the button “Compute” is to be clicked.

2.1.1 Specification of the offset of linear regression

The offset of linear regression defines the default value of the strain rate and from the nature of the hot rolling process it cannot be zero. This offset is usually between 0 and 1 s^{-1}.

2.1.2 Specification of the linear regression coefficient

The linear regression coefficient defines the slope gain of the strain rate and amplifies the actual strain with respect to the contact time. Hence the coefficient cannot be zero. This coefficient is usually between 0 and 1, and therefore the linear regression coefficient is the amplifier which weakens.

2.1.3 Specification of the strain exponent

The strain exponent is used in the exponential relation for hot yield strength computation. The strain exponent is meaningful between 0 and 1.

2.1.4 Specification of the strain rate exponent

The strain rate exponent is used in the exponential relation for hot yield strength computation. The strain rate exponent is meaningful between 0 and 1 s.

2.1.5 Specification of the grain size

The grain size considered is measured in the surface of rolled strip. The grain size on the entry of the first finishing mill (F1) is approximately 100 μm therefore the grain size is between 0 and 100 μm, as a rule. However, due to costs of measurement device and its installation the grain size is not measured in the majority of hot strip mill lines.

2.1.6 Specification of the carbon equivalent factor[3]

The carbon equivalent factor is used in the exponential relation for hot yield strength computation. The carbon equivalent factor is meaningful between 0 and 10. The carbon

[3] (1)

equivalent factor is derived from the strip temperature and the carbon equivalent, which is assessed with respect to the steel grade and chemical content. The substantial difference in carbon equivalent value is between the carbon steel and stainless steel due to considerably different chemical content. Although the carbon equivalent itself is constant for specified steel grade during the hot strip rolling the carbon equivalent factor is already slightly increasing within the hot strip rolling because of declining strip temperature. Hence the following relation for the carbon equivalent factor is applied

$$\mathrm{Carbon}_{\mathrm{equivalent}_{\mathrm{factor}}} = 0{,}126 - 1{,}75 * \mathrm{Carbon}_{\mathrm{equivalent}} + 0{,}594 * \mathrm{Carbon}_{\mathrm{equivalent}}{}^{2} + \mathrm{X(T)} \quad (1)$$

where

$$X(T) = \frac{2851 + 2968 * \mathrm{Carbon}_{\mathrm{equivalent}} - 1120 * \mathrm{Carbon}_{\mathrm{equivalent}}{}^{2}}{T + 273{,}15}$$

and carbon equivalent itself is given for microalloy or low-alloy steels

$$\mathrm{Carbon}_{\mathrm{equivalent}} = \mathrm{Carbon}_{\mathrm{content}} + \frac{\mathrm{Mn}}{6} + \frac{\mathrm{Cr} + \mathrm{Mo} + \mathrm{V}}{5} + \frac{\mathrm{Cu} + \mathrm{Ni}}{15}$$

2.1.7 Specification of the strain

The strains are derived from the material reductions and result decreasing in their values consecutively from the first to the last finishing mill. Next, the strain is applied in the exponential relation for hot yield strength computation. The strain is meaningful between 0 and 1 but from computational viewpoint the strain range is from 0 to 2.

2.1.8 Specification of the strain rate

The strain rates are derived from the linear regression and result increasing in their values consecutively from the first to the last finishing mill. Next, the strain rate is applied in the exponential relation for hot yield strength computation. The strain rate is meaningful between 0 and 10 but from computational viewpoint the strain rate range is suggested from 0 to 10.

2.1.9 Specification of the hot yield strength

The hot yield strength is computed using the following exponential function

$$\mathrm{Hot}_{\mathrm{yield}_{\mathrm{strength}}} = \mathrm{EXP}\left(\mathrm{X} + \mathrm{Carbon}_{\mathrm{equivalent}_{\mathrm{factor}}}\right) * \mathrm{g} \quad [\mathrm{MPa}] \quad (2)$$

where

$$\mathrm{X} = \mathrm{Strain}_{\mathrm{exponent}} * \mathrm{Strain} + \mathrm{Strain}_{\mathrm{rate}_{\mathrm{exponent}}} * \mathrm{Strain}_{\mathrm{rate}}$$

and

$$g = 9.81 \text{ m/s}^2$$

The hot yield strengths result increasing in their values exponentially from the first to the last finishing mill. In other words hot yield strength (2) increases with rising rolling speed (or strain rate) and vanishing strip temperature because the carbon equivalent factor rises with decreasing strip temperature[4]. Typically the hot yield strength should result between 100 and 600 MPa with respect to the steel grade and strip temperature. Mild, microalloy and carbon steel are commonly with the maximum of 300 MPa in the range of temperatures 800-900°C while stainless steel can be with the maximum of 600 MPa in the same range of temperatures. In case the previous statements are not satisfied, please, follow the instructions of the Error messages. The hot yield strength is typed in **bold face** because this variable is found out by the HSMM ver. 1.0, see Fig. 2.1.

2.2 Roll force parameters panel [5]

The roll force parameters panel comprises the geometrical factor and roll force, respectively, where the latter is naturally found out variable by the HSMM ver. 1.0 that is typed in **bold face**, see Fig. 2.1. To find out the variable typed in bold face many parameters are inherited from the Main window, first of all the number of finishing mills and the steel grade. To evaluate any change in parameter(s) of the roll force panel the button “Evaluate” is to be clicked.

2.2.1 Specification of the geometrical factor

The geometrical factor is used in the Alexander-Ford formula[6] modified by the HSMM ver. 1.0 for the roll force computation. The geometrical factor should amplify the computed roll force only moderately. Therefore the geometrical factor is suggested to be in the vicinity of 1. From the computational viewpoint the geometrical factor is designed to be between 0 and 2. Generally, the geometrical factor is an empirical parameter derived usually from experimental data and thus the geometrical factor is in the role of an adjusting or correcting constant

2.2.2 Specification of the roll force

The roll force is computed using the following Alexander-Ford formula modification

$$\text{Roll}_{\text{force}} = 2 * \text{Hot}_{\text{yield}_{\text{strength}}} * \text{Length}_{\text{contact}_{\text{arc}}} * \text{Width} * Q \quad [\text{MN}] \tag{3}$$

where Q is the geometrical factor. The computed roll force should be consecutively decreasing from the first to the last finishing mill and regarding the value order it should be 10^1 MN, i.e. 10^5 kN. Although the hot yield strength is rising during the hot strip rolling the roll force is decreasing due to substantial drop of the length of the contact arc. The roll force is typed in **bold face** because this variable is found out by the HSMM ver. 1.0, see Fig. 2.1.

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[4] (1)
[5] (1)
[6] (2)

2.3 Roll gap parameter panel

The roll gap parameter panel shows how the roll gaps must be set on the hot strip mill line to be achieved the calculated roll force on corresponding finishing mills. To find out the roll gap many parameters are inherited from the Main window, first of all the number of finishing mills and the steel grade. Also particularly the mill modulus is to be specified. To quantify the roll gap the button “Evaluate” is to be clicked.

2.3.1 Specification of the roll gap

The roll gap should result in descending values consecutively from the first to the last finishing mill. However, the last roll gap is recommended to result a little bit greater than the prelast roll gap because of better strip surface levelling[7]. Hence the last but one roll gap can be scheduled greater than the last one due to meeting the high strip quality requirement. In case the previous statements are not satisfied, please, follow the instructions of the Error messages. The relation for the roll gap computation is given as follows

$$\mathrm{Roll_{gap}} = \mathrm{Thickness_{exit}} - \frac{\mathrm{Roll_{force}}}{\mathrm{Mill_{modulus}}} \quad [\mathrm{mm}] \tag{4}$$

where the roll force must be in kN if the mill modulus is entered in kN/mm.

[7] (5)

3 Data saving & reading

The geometry schedule settings, metallurgical property settings, temperature set-up calculation, hot yield strength and roll force set-up calculations are saved to the excel file named book.xlsx. After the installation of the HSMM ver. 1.0 on the computer an empty file of “book.xlsx” is placed into the root directory of the application file (*.exe).

The aforementioned rolling set-up data are saved into the excel file after closing the New window – Roll Force Model Parameters, see Fig. 2.1. Until the Main window - Hot Strip Mill Parameters, see Fig. 1.1, is closed every another closing of the new window brings about the rolling set-up data saving into subsequent excel sheet of the file named “book.xlsx”. **Be careful to have enough empty excel sheets in the file “book.xlsx” for saving the rolling set-up data**. In other words how many excel sheets are available in “book.xlsx” so many rolling set-up data savings can be done.

Once the main window is closed and this window is launched again the process of rolling data savings is repeated from the first active sheet to possibly last available excel sheet if new window is repeatedly started and closed. **Be sure that the previously saved rolling set-up data into corresponding excel sheets are overwritten by new rolling set-up data**, therefore the previously saved rolling set-up data should be backed up before further launching the main window.

4 Help

In the program HSMM ver. 1.0 the interactive help is provided by applying the question mark in upper right-hand corner in Fig. 4.1. When applied the question mark the interactive help is provided only after clicking the item you want to show its short description. For the purposes of comprehensive help and understanding push the button “Display help” in Fig. 1.1 to open the Product Help (This document). After opening the product help any referenced web page can be downloaded. Afterwards the Product Help can be returned by clicking the button “Reload help” in the upper left-hand corner in Fig. 4.1.

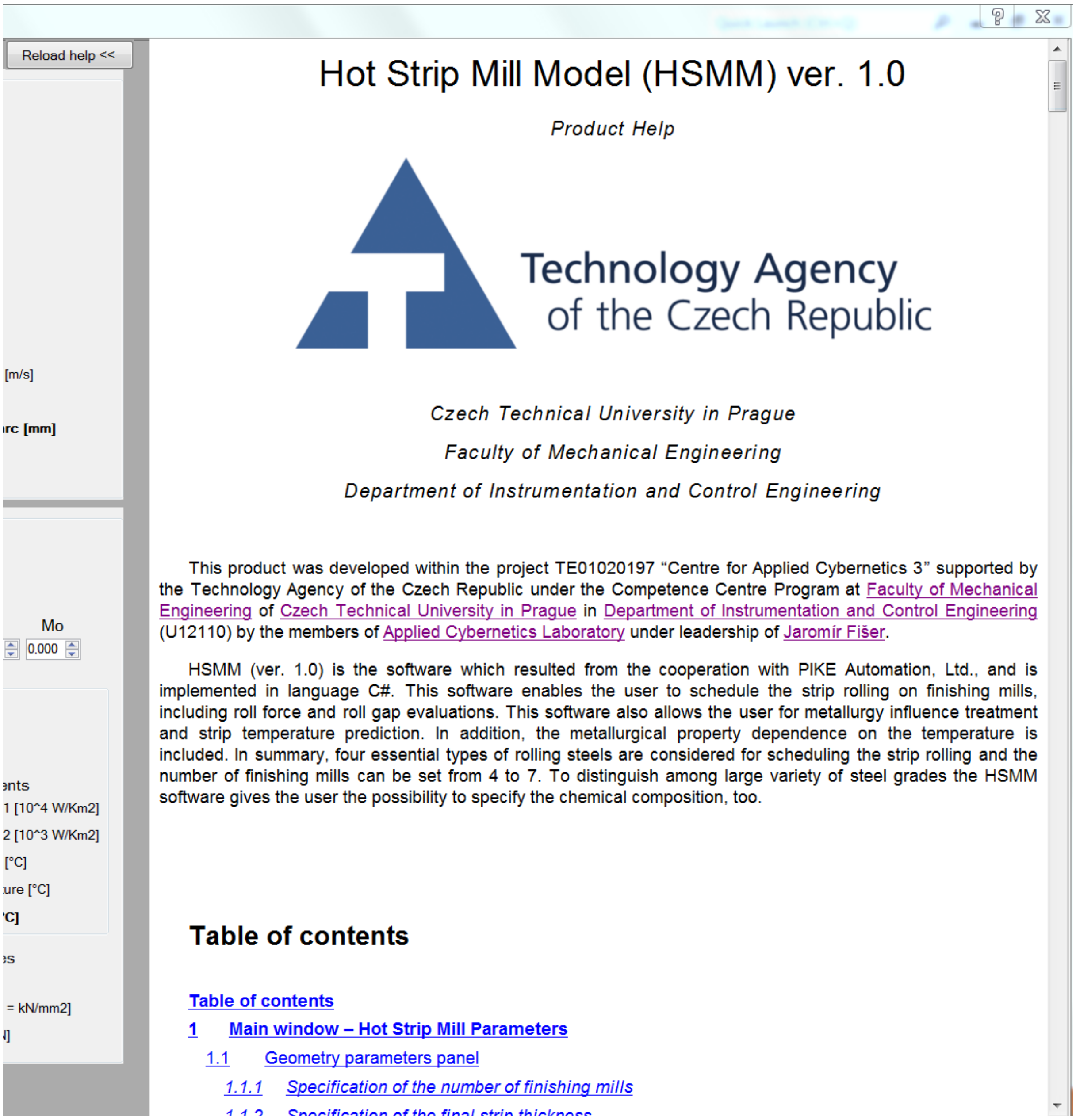

Fig. 4.1 Help Window – Right-hand side of the main window

4.1 Error messages

The error messages displayed are presented in the list of error messages ordered according to their ID. Proposed solutions to errors are provided in the list of solutions to occurred errors that are identified with given ID. The structure of ID is either MWXY or NWXY, where acronyms MW and NW represent Main Window and New Window, respectively. XY is the number of message order. The acronym FM, used in the messages' text, is derived from the term Finishing Mill(s).

4.1.1 List of error messages

The list of error messages is provided with unique ID.

Geometry panel:

ID:**MW01** The number of FM must be specified.

ID:**MW02** The final strip thickness must be specified.

ID:**MW03** The initial strip thickness must be greater than the final strip thickness.

ID:**MW04** The initial strip thickness exceeds 100 mm or final strip thickness is greater than 10 mm.

ID:**MW05** One or more material reduction(s) are zero.

ID:**MW06** The material reduction on the last FM is higher than the reduction on the prelast FM.

ID:**MW07** The material reduction on the last FM is negative.

ID:**MW08** The circumferential speed of work roll on F1, F2 or F3 is set to zero.

ID:**MW09** The circumferential speed of work roll on F4, F5, F6 or F7 is set to zero.

ID:**MW10** The forward slip or circumferential speed on F1 is zero-valued.

ID:**MW11** The forward slip on F1, F2 or F3 is set to zero.

ID:**MW12** The forward slip on F4, F5, F6 or F7 is set to zero.

ID:**MW13** The forward slip on one or several FM results greater than 100 %.

ID:**MW14** The strip width on F2, F3, F4, F5, F6 or F7 cannot be set to zero.

ID:**MW15** The strip width on actual FM is not the same or higher than the strip width on previous FM.

ID:**MW16** The strip length(s) between F1 and F2, F2 and F3, F3 and F4, F4 and F5, F5 and F6, or F6 and F7 must be specified.

ID:**MW17** The work roll diameter(s) on F1-F4, F1-F5, F1-F6, or F1-F7 are not descending in their values.

ID:**MW18** The length(s) of contact arc on F1, F2, F3, F4, F5, F6 or F7 cannot result in zero.

ID:**MW19** The length of contact arc cannot be greater than the work roll radius (half of the roll diameter).

ID:**MW20** The contact time could not be computed due to dividing by zero.

Metallurgy panel:

ID:**MW21** The steel grade must be specified.

ID:**MW22** The final strip temperature must be specified.

ID:**MW23** The initial strip temperature must be greater than the final strip temperature.

ID:**MW24** The initial strip temperature exceeds 1500 °C or final strip temperature is greater than 1000 °C.

ID:**MW25** One or more exit strip temperature(s) are zero.

ID:**MW26** Adjacent exit strip temperatures resulted the same on F1, F2, F3, F4, F5, F6 or F7.

ID:**MW27** The temperature on the exit of the last FM is higher than the temperature on the exit of the prelast FM. For more details see Help section with Error messages.

ID:**MW28** The temperature on the exit of the last FM is negative.

ID:**MW29** The ambient temperature is equal or greater than the final strip temperature.

ID:**MW30** The roll surface temperature is equal or greater than the final strip temperature.

ID:**MW31** At least the carbon content from the chemical content should be specified.

ID:**MW32** The density of selected steel has to be specified.

ID:MW33 The mill modulus is not specified somewhere on F1, F2, F3, F4, F5, F6 or F7. Hence the roll gap on corresponding FM cannot be evaluated.

ID:**MW34** The Young modulus is not specified somewhere on F1, F2, F3, F4, F5, F6 or F7. Hence the flattened roll diameter on corresponding FM cannot be evaluated.

ID:**MW35** The material hardness is not specified somewhere on F1, F2, F3, F4, F5, F6 or F7.

Hot yield strength panel:

ID:**NW01** The number of finishing mills, previously selected, is exceeded by the user entries.

ID:**NW02** The strain rate somewhere on F1, F2, F3, F4, F5, F6 or F7 resulted zero.

ID:**NW03** The strain somewhere on F1, F2, F3, F4, F5, F6 or F7 exceeds 2. Usually, this value should be less than 1.

ID:**NW04** The strain rate somewhere on F1, F2, F3, F4, F5, F6 or F7 exceeds 10. Usually, this value should be less than 5.

ID:**NW05** The hot yield strength somewhere on F1, F2, F3, F4, F5, F6 or F7 exceeds 1000 MPa. Usually, this value should be less than 300 MPa, and not higher than 600 MPa.

Roll force panel:

ID:**NW06** The roll force somewhere on F1, F2, F3, F4, F5, F6 or F7 exceeds 100 MN. Usually, this value should be less than 50 MN.

Roll gap panel:

ID:**NW07** The roll gap somewhere on F1, F2, F3, F4, F5, F6 or F7 exceeds 100 mm. Usually, this value should be less than 50 mm.

ID:**NW08** The roll gap somewhere on F1, F2, F3, F4, F5, F6 or F7 results negative. Verify correct setting of the mill modulus that commonly is of order 10^4 kN.

4.1.2 List of error solutions

The list of solutions to errors, identified with unique ID, is provided below.

Geometry panel:

ID:**MW05** Check if the number of non-zero reductions is in the agreement with the number of FM. Also the final strip thickness must be specified.

ID:**MW06** Commonly this error is caused by wrong reduction schedule on the first FM. The material reductions should be scheduled on these FM higher than they actually are. For more details see section Specification of material reduction.

ID:**MW07** Commonly this error is caused by wrong reduction schedule on the first FM. The material reductions should be scheduled on these FM lower than they actually are. As a result of this wrong reduction schedule it is increasing exit strip thickness over the FM! *Be careful because the negative material reductions inevitably lead to negative strains but this is physically impossible !* For more details see section Specification of the material reduction.

ID:**MW09** Check if the number of non-zero circumferential speeds is in the agreement with the number of FM. If not check also the number of non-zero forward slips from which the circumferential speeds are estimated. For more details see section Specification of the circumferential speed and forward slip. Of course, if the errors with ID: **MW05** and **MW08** occurred previously they must be resolved first.

ID:**MW10** You should specify both a forward slip and a circumferential speed on F1, and corresponding values of computed variable (slip or speed) on other FM should be set to zero. For more details see section Specification of the circumferential speed and forward slip.

ID:**MW12** Check if the number of non-zero forward slips is in the agreement with the number of FM. If not check also the number of non-zero circumferential speeds from which the forward slips are estimated. For more details see section Specification of the circumferential speed and forward slip. Of course, if the errors with ID: **MW05** and **MW11** occurred previously they must be resolved first.

ID:**MW13** This is the case when the forward slip is estimated from the knowledge of the circumferential speed. However, proper setting of circumferential speed is really hard work hence follow the instructions of the section Specification of the circumferential speed and forward slip.

ID:**MW14** The rule of filling out the strip widths is presented in Specification of the strip width.

ID:**MW16** The rule of filling out the strip lengths is presented in Specification of the strip length.

ID:**MW18** Check either the value of corresponding roll diameter(s) or the value of corresponding material reduction(s) that should be non-zero. For more details see section Specification of the length of contact arc. Of course, if the error with ID:**MW07** occurred previously it must be resolved first.

ID:**MW20** This error is because the circumferential speed or exit thickness on one or more FM resulted zero. Of course, if the error with ID: **MW09** occurred previously it must be resolved first.

Metallurgy panel:

ID:**MW25** Check if the number of non-zero exit strip temperatures is in the agreement with the number of FM. Also the final strip temperature must be specified.

ID:**MW26** Check overall heat transfer coefficients to be set non-zero on corresponding FM.

ID:**MW27** Generally, methods of exit strip temperature computation does not permit this error. For more details see section Specification of the exit strip temperature.

ID:**MW28** It would be possible only when the final strip temperature is set negative! However, this possibility is automatically prohibited by the HSMM ver. 1.0. Other occurrences of this error could arrive at two ways, see errors with ID: **MW29** and **MW30**. The first one is that the ambient temperature is set higher than the final strip temperature and the second one that the roll surface temperature is set higher than the final strip temperature.

ID: **MW29** See the error solution to ID:**MW28**.

ID: **MW30** See the error solution to ID:**MW28**.

ID:**MW32** The density is required to be set nonzero when the temperature prediction model is applied to exit strip temperature computation. For more details see section Specification of the exit strip temperature.

ID:**NW01** This error is related to the fact that user attempts to enter values of variables in the New Window (NW) which should be not evaluated due to selected number of finishing mills. In other words the user is already behind this number.

ID:**NW02** The linear regression parameters must be set to nonzero values.

ID:**NW05** For more details see section Specification of the hot yield strength.

ID:**NW06** For more details see section Specification of the roll force.

ID:**NW08** Verify correct setting of the mill modulus that commonly is of order 10^4 kN.

5 Bibliography

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3. **EN 1993-1-2:2005.** *Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design.* Praha : Český normalizační institut, 2006.

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5. **Watanabe, T., Narazaki, H., Kitamura, A., Takahashi, Y., Hasegawa, H.** A new mill-setup system for hot strip rolling mill that integrates a process model and expertise. *IEEE International Conference on Systems, Man, and Cybernetics: Computational Cybernetics and Simulation.* Orlando, FL : IEEE, 12-15 October, 1997, Vol. 3, pp. 2818 - 2822.