Analytical Approach to determine Gripper Pretensioning Force for Driving Tunnels with a Gripper TBM

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Gripper pretensioning force represents an essential parameter for deciding on the application of a Gripper TBM for driving a tunnel in hard rock. This article deals with a new approach for calculating a simplified evaluation of the gripper pretensioning force involving only a few initial parameters.

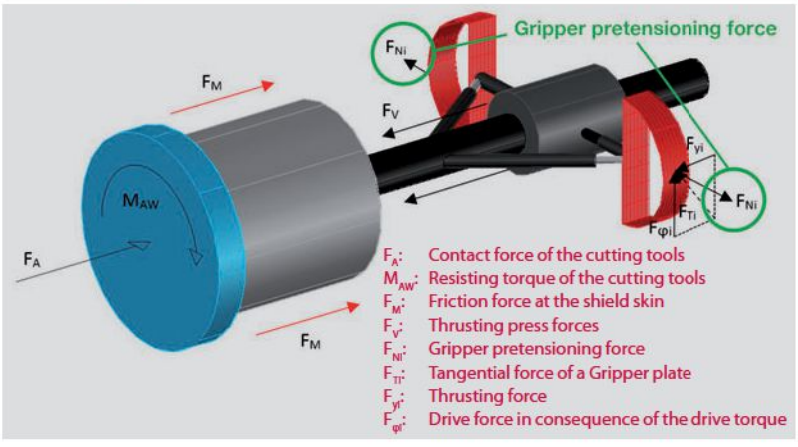
Tunnelling • Driving • TBM • Gripper • Calculation method • Data analysis

1 Introduction

A Gripper TBM is suitable for application in hard rock with average to high tool life. The planning and production costs are higher for mechanised tunnelling compared with conventional NATM. This difference in cost can only be compensated for becoming economically acceptable through higher rates of advance. The rate of advance depends on various factors. Around the cutter head the rate of extraction correlates with the strength of the rock. The greater the strength of the rock is, the higher the forces are that must be produced at the cutter head, with the wear on the hard rock discs correspondingly higher. The lower the strength of the rock, the lower are the forces acting at the cutter head as well as the wear on the hard rock discs and the higher the rate of advance. In order to produce the forces around the cutter head, the gripper pads are pretensioned in the rock and conduct the reaction forces into the rock. The lower the strength of the rock, the greater is the danger that the rock strength does not suffice, the reaction forces cannot be conducted into the rock and that the rock fractures. It must be observed however that lower reaction forces also accompany low rock strength, as the forces, which are required at the face in order to remove the rock are correspondingly less. The strength of the rock plays a decisive role for installing the support agents within the unsecured rock area. In the case of lower rock strength more complex support agents are required than for higher rock strength. Ideally no support agents are needed in the case of rock with high strength, and here too the rate of advance and the economy are correspondingly higher.

The gripper pretensioning force F_{Ni} (Fig. 1) represents an important parameter for deciding on applying a Gripper TBM. In order to be able to estimate the contact force for pretensioning a Gripper TBM in a straightforward manner, an analytical calculation approach was developed, which is presented in this report.

Fig. 1: Schematic presentation of the thrusting forces and drive torques of a Gripper TBM [1]



2 Existing Calculation Approach for Estimating the Gripper Pretensioning Force

In 2006, WITTKE published a calculation approach to estimate the Gripper pretensioning force F_{Ni} [2]. The tangential force F_{Ti} is in this case activated as a frictional force via the Gripper pretensioning force F_{Ni} of a Gripper plate i (Fig. 1). Given uniform pretensioning of all Gripper plates. the following calculation approach is attained [2]:

$$F_{Ni} = \frac{\eta_P * F_{Ti}}{\mu_H} \quad \text{.....(1)}$$

In this case η_p represents a safety factor. The static friction coefficient μ_H between the Gripper plates and the rock is determined as follows [2]:

$$\mu_H = \tan\delta \quad \text{.....(2)}$$

The wall angle of friction δ is generally represented as 2/3rds of the angle of friction φ of the rock. The tangential force F_{Ti} of a Gripper plate is obtained as the outcome of the tangential force of a Gripper plate on account of the thrusting force F_{yi} and the tangential force of a Gripper plate based on the drive torque $F_{\varphi i}$ (Fig. 1).

$$F_{Ti} = \sqrt{F_{yi}^{\,2} + F_{\varphi i}^{\,2}} \quad \text{.....(3)}$$

The quotient from the necessary thrusting force F_{Tb} and the number of Gripper plates k is taken for calculating

the tangential force of a Gripper plate resulting from the thrust cylinder force F_{yi}.

$$F_{yi} = \frac{F_{Tb}}{k} \quad \text{.....(4)}$$

The necessary thrusting force F_{Tb} consists of the sum of the contact forces of all discs F_c. the resistance force from the floor shoe friction F_R and a safety margin ΔF [2].

$$F_{Tb} = F_c + F_R + \Delta F \quad \text{.....(5)}$$

The following equation provides the tangential force of a Gripper plate resulting from the drive torque $F_{\varphi i}$:

$$F_{\varphi i} = \frac{M_D}{2D} \quad \text{.....(6)}$$

In the equation M_D represents the necessary drive torque and D the cutter head diameter. The necessary drive torque M_D is determined by the sum of the resistance torque of the discs and the scrapers M_c as well as a safety margin ΔM:

$$M_D = M_c + \Delta M \quad \text{.....(7)}$$

Consequently nine parameters are required for determining the necessary Gripper pretensioning force F_{Ni} according to [2] resulting in a correspondingly high outlay during the calculation process.

3 Newly developed Calculation Approach for Assessing the Contact Force

The following possible interrelationships were analysed among other things by means of regression analyses based on a large number of published research results as well as data from excavations using a Gripper TBM:

- Comparison of the installed thrusting force with the relevant cutter head diameter
- Influence of the disc contact pressure on the necessary Gripper pretensioning force
- Influence of the cutter head diameter on the necessary Gripper pretensioning force given varying disc contact force

In Fig. 2 the influence of the penetration rate p per cutter head rotation U on the necessary Gripper pretensioning force is visualised. The penetration rate p was in the process determined in keeping with [3], in the case of which the equation [8] relating to the rolling friction coefficient of the discs μ_R depending on the disc diameter d is lent consideration.

$$\mu_R = \sqrt{\frac{p\,[\frac{mm}{U}]}{d[mm] \cdot p\,[\frac{mm}{U}]}} \quad \text{.....(8)}$$

The studies as well as Fig. 2 show a linear connection between the penetration rate p and the necessary

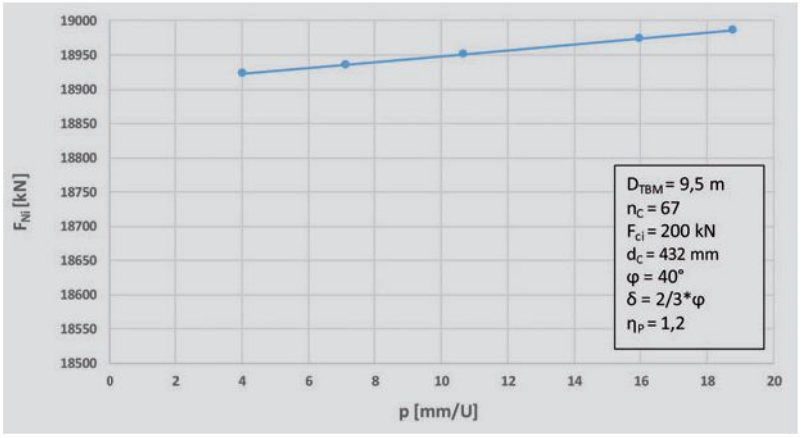


Fig. 2: Influence of the penetration rate p (per cutter head rotation U) on the necessary Gripper pretensioning force F_{Ni} (per Gripper shoe) [1]

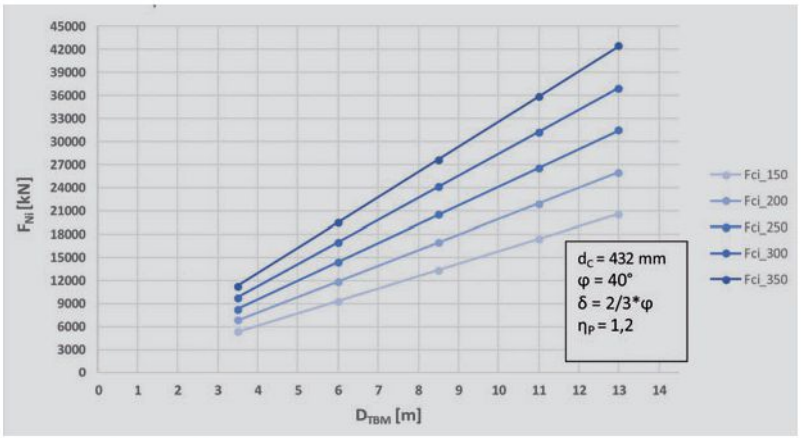


Fig. 3: Influence of the cutter head diameter D_{TBM} on the necessary Gripper pretensioning force F_{Ni} (per Gripper shoe) given varying disc contact force F_{ci} [1]

Gripper pretensioning force F_{Ni}. In this respect it can be clearly discerned in Fig. 2 that the penetration rate fails to exert any significant influence on determining the necessary Gripper pretensioning force. Given a difference in the penetration rate of approx. 14 mm/U the necessary Gripper pretensioning force increases by only some 60 kN.

Fig. 3 shows the influence of the cutter head diameter on the necessary Gripper pretensioning force given varying disc contact force. Here the analyses indicate that the magnitude of the disc contact force F_{ci} substantially influences the calculation of the necessary Gripper pretensioning force. The influence of the cutter head diameter is also evident in Fig. 3. Thus in the case of larger cutter head diameters owing to the greater number of discs the disc contact force exerts a greater influence on the magnitude of the necessary Gripper pretensioning force. As in the case of the penetration rate, here too a linear connection between the cutter head diameter and the necessary Gripper pretensioning force is evident.

It can be generally concluded on the basis of the analyses that were undertaken that in order to obtain a preliminary estimate of the necessary Gripper pretensioning force without the precise calculation approach in

accordance with [2], both the number of discs as well as the selected or necessary disc contact force is required. Both parameters can be assumed at the start of a tunnel project e. g. via the cutter head diameter or the optimal field of application of the discs. Towards this end the relevant tangential Gripper pretensioning forces F_{Ti} in keeping with [2] were determined for the range of parameters contained in Table 1. Table 2 includes the values obtained from these calculations, $\eta_P = 1.2$ was taken as the safety coefficient.

The quotient Q_{FF} from the disc contact force F_{ci} and the resultant tangential force of a gripper F_{Ti} is compared with the number of discs n_c for the investigations. Table 2 displays the outcome of this comparison. Fig. 4 shows the determined values. The resultant regression curve clearly takes on the form of a potential function.

The potential function of the determined regression curve is provided in equation (9).

$$Q_{FF} = 1{,}8488 * n_c^{-1{,}018} \quad \text{.....(9)}$$

The relevant coefficient of determination for the regression curve amounts to $R^2 = 0.993$. This results in the following equation (10) for obtaining a preliminary estimation of the necessary contact force for Gripper pretensioning:

$$F_{Ni} = \frac{F_{ci}}{1{,}8488 * n_c^{-1{,}018}} * \frac{\eta_P}{\mu_H} * \beta_K \quad \text{.....(10)}$$

In this connection the number of discs n_c can be determined in keeping with the following approach from [4] via the cutter head diameter D_{TBM}:

Table 1: Range of parameters

Parameter		Value
Cutter head diameter D_{TBM}	[m]	3.5 bis 13
Penetration rate p	[mm/U]	6 bis 18
Disc size d_c	[mm]	432
Disc contact force F_{ci}	[kN]	150 bis 350
Number of grippers	[-]	2

Table 2: Tangential Gripper pretensioning forces F_{Ti} according to [2] or via regression function and corresponding correction coefficients

D_{TBM} [m]	n_c	F_{ci} [kN]	$Q_{FF} = F_{ci}/F_{Ti}$ [-]	F_{Ti} according to [2] [kN]	F_{Ti} (regression function) [kN]	Correction coefficient β_{Ki} [-]
3.50	**25**	150	0.06706	2236.71	2105.58	1.062
6.00	42	150	0.03834	3911.87	3644.76	1.073
8.50	60	150	0.02685	5587.51	5195.89	1.0754
11.00	77	150	0.02065	7262.26	6755.37	1.0750
13.00	91	150	0.01744	8603.04	8007.66	1.074
3.50	**25**	200	0.07011	2852.79	2807.44	1.016
6.00	42	200	0.04026	4967.30	4859.68	1.022
8.50	60	200	0.02824	7082.81	6927.85	1.022
11.00	77	200	0.02175	9196.44	9007.15	1.021
13.00	91	200	0.01837	10889.40	10676.88	1.020
3.50	**25**	250	0.07204	3470.25	3509.31	0.989
6.00	42	250	0.04149	6024.83	6074.60	0.992
8.50	60	250	0.02913	8581.14	8659.81	0.991
11.00	77	250	0.02245	11134.19	11258.94	0.989
13.00	91	250	0.01897	13180.19	13346.10	0.988
3.50	**25**	300	0.07337	4089.12	4211.17	0.971
6.00	42	300	0.04235	7084.51	7289.52	0.972
8.50	60	300	0.02975	10082.59	10391.77	0.970
11.00	77	300	0.02294	13075.62	13510.73	0.968
13.00	91	300	0.01939	15475.54	16015.31	0.966
3.50	**25**	350	0.07432	4709.42	4913.03	0.959
6.00	42	350	0.04296	8146.40	8504.44	0.958
8.50	60	350	0.03021	11587.22	12123.73	0.956
11.00	77	350	0.02330	15020.81	15762.52	0.953
13.00	91	350	0.01969	17775.55	18684.53	0.951

Table 3: Deviation of the estimated tangential Gripper pretensioning force from the tangential Gripper pretensioning force worked out according to [2]

D_{TBM} [m]	n_c	F_{ci} [kN]	F_{Ti} according to [2] [kN]	Corrected F_{Ti} (regression function) [kN]	Deviation [%]
3.50	**25**	150	2237	2246	-0.43
6.00	42	150	3912	3888	0.60
8.50	60	150	5588	5543	0.79
11.00	77	150	7262	7207	0.76
13.00	91	150	8603	8543	0.70
3.50	**25**	200	2853	2880	-0.96
6.00	42	200	4967	4986	-0.37
8.50	60	200	7083	7107	-0.35
11.00	77	200	9196	9241	-0.48
13.00	91	200	10889	10954	-0.59
3.50	**25**	250	3470	3493	-0.65
6.00	42	250	6025	6046	-0.35
8.50	60	250	8581	8619	-0.44
11.00	77	250	11134	11206	-0.64
13.00	91	250	13180	13283	-0.78
3.50	**25**	300	4089	4089	0.01
6.00	42	300	7085	7077	0.10
8.50	60	300	10083	10089	-0.07
11.00	77	300	13076	13117	-0.32
13.00	91	300	15476	15549	-0.47
3.50	**25**	350	4709	4671	0.82
6.00	42	350	8146	8086	0.75
8.50	60	350	11587	11527	0.52
11.00	77	350	15021	14986	0.23
13.00	91	350	17776	17764	0.06

$$n_c \approx 7\, D_{TBM} \quad \text{.....(11)}$$

The correction coefficient β_K serves to correct deviations from the regression analysis for equation (10). This can also be established via a potential function. Towards this end the individual correction coefficients from the regression analysis for Q_{FF} are related to the disc contact force F_{ci} and evaluated (Fig. 5).

The dependence of the correction coefficient β_K on the disc contact force F_{ci} can be described in this case through the following potential regression function with a coefficient of determination of $R^2 = 0.982$:

$$\beta_K = 2{,}1089 * F_{ci}^{-0{,}136} \quad \text{.....(12)}$$

As a result of the correction coefficient the deviation of the estimated Gripper pretensioning forces from the values determined by precise calculation according to [2] constantly amounts to less than ±1% (Table 3). The newly developed calculation approach only requires three parameters instead of the nine for the precise calculation approach according to [2] thus making it easier to determine the Gripper pretensioning force for a Gripper TBM.

4 Summary

In order to be able to produce the necessary thrusting forces to act on the cutter head of a Gripper TBM it is essential to exert a contact force on the Gripper pretensioning system. An explicit calculation approach according to [2] exists to assess the necessary Gripper pretensioning force. A further calculation method was devised based on regression analyses for working out the necessary Gripper pretensioning force for a Gripper TBM. In the case of this calculation approach the Gripper pretensioning force can be estimated in a straightforward manner by means of the parameters for the disc contact force *Fci*. the number of discs n_c as well as the rock's angle of friction φ.

5 References

[1] Khadr, W.: Analysen zu den Einsatzgrenzen von Gripper-TBM. Masterarbeit an der Hochschule Darmstadt, not published, 2017.

[2] Wittke, W.: Statik und Konstruktion maschineller Tunnelvortriebe. WBI-PRINT 6, VGE-Verlag Glückauf GmbH, Essen, 2006.

[3] Roxborough, F. F.; Phillips, H. R.: Rock excavation by disc cutter. International Journal of Rock Mechanics and Mining Sciences, Volume 12, Issue 12, 1975, pp. 361-366.

[4] Leitner, W.: Baubetriebliche Modellierung der Prozesse maschineller Tunnelvortriebe im Festgestein, Von der Penetration zur Vortriebsgeschwindigkeit. Leopold-Franzens-Universität Innsbruck Baufakultät - Architektur und Bauingenieurwesen, 2004.

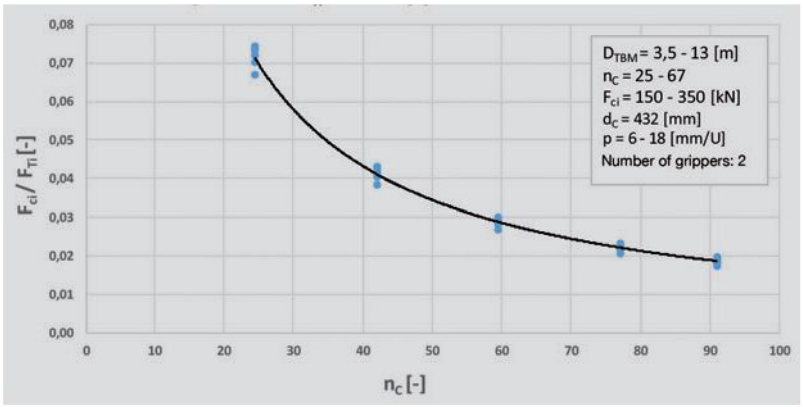


Fig. 4: Comparison of the quotients Q_{FF} from the disc contact force F_{ci} and the tangential force F_{Ti} of a gripper with the number of discs n_c

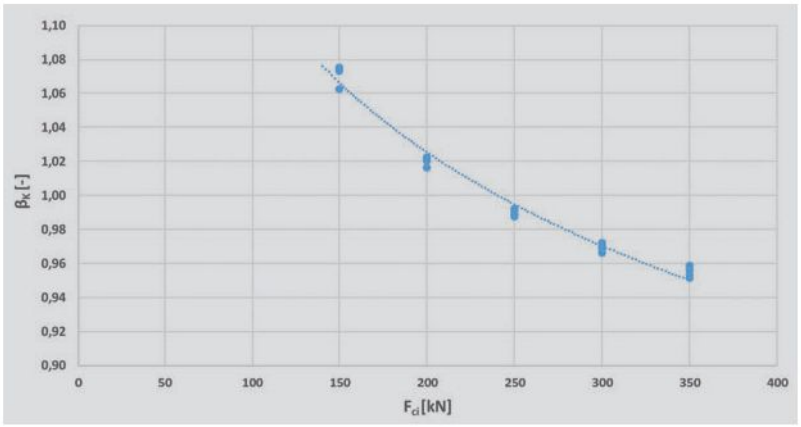


Fig. 5: Path of the regression function for the correction coefficient β_K

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