

Title: Stress Analysis of Gun Breech Block for Gun Design Applications

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This study presents a detailed Finite Element Analysis (FEA) of a breech block featuring a buttress thread, aimed at understanding the stress distribution under various loading conditions. Buttress threads, known for their high load-bearing capacity and asymmetrical profile, are commonly used in applications where high axial loads are required, such as in hydraulic systems and fasteners. Utilizing *Abaqus*, a comprehensive stress analysis was conducted on the threaded block to assess critical factors such as stress concentration, deformation patterns, and the overall integrity of the design under different loading scenarios.

The model was created using precise geometric definitions of the buttress thread, including the lead angle and asymmetric thread profiles. The material properties were assigned based on realistic parameters commonly used in industrial applications, this material was steel 4340. Static loading conditions were applied to simulate operational stresses, and a fine mesh was employed to capture the detailed stress distribution around the thread roots and flanks, where stress concentrations are typically highest.

The results revealed that the buttress thread design effectively distributes axial loads along the inclined surface, minimizing stress concentrations compared to conventional thread forms. This design of the breech block based on the buttress thread is extremely important when it comes to the gun design and it is a good reason why the buttress thread is design in this way for most guns.

However, significant stress concentration was observed at the root of the thread, necessitating potential design optimizations. This analysis demonstrates the efficacy of buttress threads for high-load applications in gun designs, with the FEA results providing valuable insights for further refinement of the design.

The study validates the use of *Abaqus* in performing detailed stress analysis of complex geometries, showcasing its capability to predict critical stress regions and potential failure points. Recommendations for future work include fatigue analysis and exploring the effects of varying thread dimensions on stress distribution to judge the novelty in our work.

INTRODUCTION

Military engineers have been working on innovative designs for gun breech blocks, which are an integral part of gun design. This design revolution has been discussed in detail, with a focus on the various designs that have evolved over the years.

Roy et al. (2017) highlight that the breach mechanism involves the mechanical coupling of parts with the firing circuit. The circuit operational requirement is crucial in this system and is determined by the rate of fire, regardless of the operation method. The type of bridge mechanism and loading design also play a significant role. The authors noted that granite steel with a refined microstructure is typically used for the breach mechanism due to its high fatigue life, with sliding wedge breach blocks commonplace. However, there are other breech types including screw breeches. This study specifically investigates the screw-type breech block mechanism to fill in the missing hole that has existed in literature with limited research in screw-type breeches. The paper aims to analyse the operational efficiency and durability of different breech block designs and to establish a comprehensive understanding of their mechanical properties. The approach taken includes the use of Finite Element Analysis (FEA) modelling using *Abaqus* for stress analysis. Different constraints were also tested to assess their impact on the breech block's performance.

MATERIAL PROPERTIES

For any material and body, induced stresses should be within the allowable limits for the material to be used. There needs to be a comparison between the yield strength and the ultimate tensile strength of the material to ensure safety and of course reliability. An example calculation has been done here to later apply onto computational models.

Example Calculation

Assume an axial load P of 10,000 N, and a major diameter of 20 mm, a minor diameter of 17 mm, thread height of 2 mm and 5 engaged threads.

For this purpose we shall first, calculate the average diameter, as follows:

$$d_{avg} = d + d_{12} = 20 + 172 = 18.5 \text{ mm}$$

After this we calculate the effective load bearing area:

$$A = \pi * d_{avg} * h * n = \pi * 18.5 * 2.5 = 581.19 \text{ mm}^2$$

After calculation of the effective load bearing area we calculate the nominal axial stress as follows:

$$\sigma = P / A = 10,000 / 581.19 = 17.2 \text{ MPa}$$

Subsequently, we apply a stress concentration factor:

$$\sigma_{actual} = K * t * \sigma = 2 * 17.2 = 34.4 \text{ MPa}$$

The above example is much simplified and in practice, more detailed calculations are required considering the specific thread profile geometry purpose, the material properties and the exact loading conditions.

Table 1 shows a summary of the stresses that have been used in the above calculations, as these terms will be employed throughout our work.

TABLE 1: STRESS DESCRIPTION OF THE VARIOUS STRESSES USED IN THE DESCRIPTIONS ABOVE.

VARIABLE	SYMBOL	FORMULA	DESCRIPTION
Axial Stress	σ_a	$\sigma_a = F / A$	Stress acting along the axis of an object, where F is the axial force and A is the cross-sectional area.
Nominal Stress	σ_n	$\sigma_n = P / A_0$	Approximate stress in the undeformed cross-sectional area, where P is the applied load and A_0 is the initial cross-sectional area.
Shear Stress	τ	$\tau = F_s / A_s$	Stress that acts parallel to the surface, where F_s is the shear force and A_s is the shear area.

It's important to point out the standards for calculating the stresses on buttress profile threads (Table 2) – although analytical solutions are not considered here. However, it would be our aim to apply these standards for the current and future modelling approaches.

TABLE 2: STANDARDS FOR BUTTRESS PROFILE DESIGNS.

STANDARD	TITLE	DESCRIPTION
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ISO 2904:1977	ISO metric screw threads - Buttress threads - Design profiles	Specifies the design profiles for ISO metric buttress threads, including dimensions and tolerances.
ISO 5408:2009	Screw threads vocabulary	Provides the vocabulary for screw threads, standardizing the terminology used in the industry.
ASME B1.9-1973 (R2017)	Buttress Inch Screw Threads	Covers the dimensions, tolerances, and general design of buttress threads for inch-based measurements.
ASME B1.5-1997 (R2012)	Acme Screw Threads	Primarily for Acme threads, but also contains relevant information on stress calculations and thread engagement that can be adapted for buttress threads.
DIN 513:1956	Buttress Threads - Design Profiles	Includes detailed profiles and calculation methods for buttress threads, provided by the German Institute for Standardization.
BS 1657:1960	Buttress threads - Dimensions	Specifies dimensions and design details for buttress threads, according to British Standards.

Here, we discuss the load distribution in a buttress thread. As outlined in Table 3, key parameters in the load distribution in a buttress thread are the load bearing and trailing faces, thread root and crest, and uniform load distribution. The description details that the steep load bearing face is perpendicular to the thread axis, and that it predominantly, carries the axial load – transmitting it directly along the screws length. This minimizes the bending stresses and maximizes the axial load capacity.

TABLE 3: DESCRIPTION OF DIFFERENT ASPECT OF LOAD DISTRIBUTIONS WITHIN THE BUTTRESS THREAD.

Aspect	Description
Load-Bearing Face	The steep load-bearing face is nearly perpendicular to the thread axis. It predominantly carries the axial load, transmitting it directly along the screw's length, minimizing bending stresses and maximizing axial load capacity.
Trailing Face	The trailing face is angled more gently and does not typically carry significant loads under normal conditions. Its primary role is to provide clearance and facilitate easier engagement and disengagement of the threads.
Thread Root and Crest	The root of the thread experiences compressive stresses due to load transfer from the load-bearing face. The crest of the mating thread also experiences contact stresses, but these are generally lower.
Uniform Load Distribution	In a well-designed buttress thread, the load distribution along the load-bearing face should be relatively uniform. Imperfections or misalignments can cause localized stress concentrations, leading to premature wear or failure.

This simulation considers only an elastic model, incorporating the elastic properties of steel. No plasticity, non-linearity, or additional material behaviors have been included in this analysis. The results reflect purely elastic deformation under the applied loading conditions, ensuring that the material response remains within the linear elastic range.

MODEL DESIGN AND MEASUREMENT

Impression of breech block (from an arbitrary real-world system) were collected using a RepliSet-GF1, manufactured by Struers. The impression was then shadow-graphed to perform measurements on the breech (Figure 1). It was an interesting finding that the buttress thread on the breech block was perhaps custom made and had a very different angle from the standards. Namely there are three standards used for buttress threads ISO 2904, ANSI/ASME B1.9, and DIN 513, which are worth discussing in here, [1], [2], [3]. ISO 2904 [1], specifies the basic dimensions, including pitch, major diameter, and minor diameter for the buttress threads, and then these are used in power transmission and various high-load applications. The remaining two standards follow similar lines and concentrate on the measurements of the buttress thread as well. However, the buttress thread in our shadow graph is based on no standards and was custom made.



Figure 1: Resin Impression Planted on The Breech Block (Left) And Shadowgraph (Right)

COMPUTATIONAL METHOD

A step-wise approach was taken to develop the model using a two-tooth model first to start off with. Mesh sensitivity studies were performed on all models, with Figure 2 representing the resultant FEA model developed here.

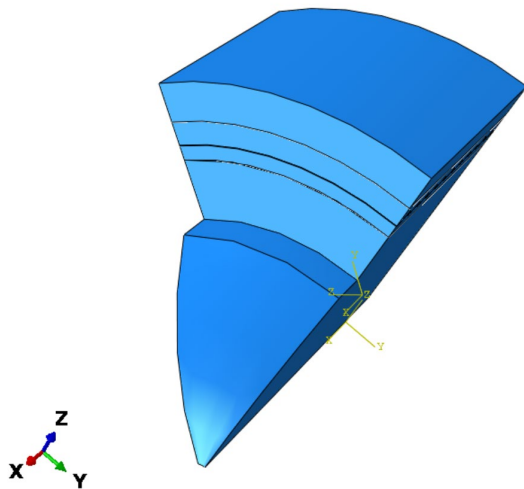


Figure 2: FEA Model of an element of the gun-system breech developed in ABAQUS CAE

REDUCED MODELS FOR CONTACT TUNING

A three-dimensional reduced contact model was also developed to view the effect of a single tooth, in these models the tooth is symmetrical, and a stepwise approach is used. The buttress profile has not been explicitly modelled. The model represents the definition of ties and contact, moreover, tangential behaviour is applied as hard contact, and normal behaviour is taken to be frictionless. Figure 3 shows the Von Mises Stress distribution in the reduced model for 1 mm mesh size. The maximum Von Mises Stress showed a difference of 5.5 % compared from the refined mesh models. This is therefore taken to be under 10%. The stress distribution though along the tooth seemed symmetrical. The three-dimensional model is developed using one-eighth of the models, with an associated mesh sensitivity is also performed for the 3D model.

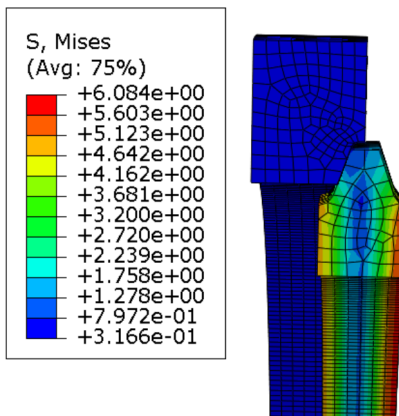


Figure 3: Von Mises Stress on two tooth Model

A.K. Singh and P. Prasad (2019), [4], have focused a paper on the stress analysis of buttress thread forms, using Finite Element Analysis, FEA, mainly focusing on the stress distribution. A good contribution of this work is that thread angle and root radius greatly influence the stress concentration and load distribution of the threads. However, the authors used Ansys as the primary code, whereas we are using Abaqus in our simulations. The outcomes from the investigations mainly showed that a smaller root radius results in higher stress concentrations, and the angle of the load-bearing flank if steeper will reduce the stress concentration as well. Similarly, A. Kavith et.al, [5] have described their work on buttress connections using the finite element method. However, their research arguably had some drawbacks, in that the experimental validation of their findings has not been done. Moreover, there is no wider discussion around impacts on breech development.

In our terminology, we will refer to the application of pressure as the pressure face. For the applied pressure HMSOV should have been used. To replicate the HMSOV an online open source paper is used [6], in our actual simulations, however, the results presented in this paper are based on a unit displacement application instead.

PROBLEMS CONSIDERED

Key research questions that this study is involved in addressing are focused on design of an optimal breech. They include exploring the stress around the tooth, and the maximum strength as a function of axial distance away from the pressure or displacement face. We are also interested in how many teeth there are in the breech design and whether the last tooth takes any load? Pitch distance is also important here,

with a particular thread pitch and tooth height. Therefore, what is the optimum pitch in the tooth form? Moreover, how much tolerance you can have (as a function of pitch)? Also, how much misalignment can we have on one tooth circle, so that when its deflected, until more teeth are touching, we avoid overstress? However, this research focused on the stress distribution as the initial step in this paper.

FULL THREE-DIMENSIONAL MODEL WITH BOUNDARY CONDITIONS

A full three-dimensional model is developed, using two different boundary conditions as listed under.

Case A: The constraints here are applied on the ZY face of the barrel

Case B: In this case, the constraints are applied on the outer surface

In both cases symmetry constraints are also applied.

STRESS CONCENTRATION VARIATION WITH VARIABLE CONSTRAINTS

It was noticed that the stress changes with variable constraints. However, a common area remains the high stress along the tooth areas.

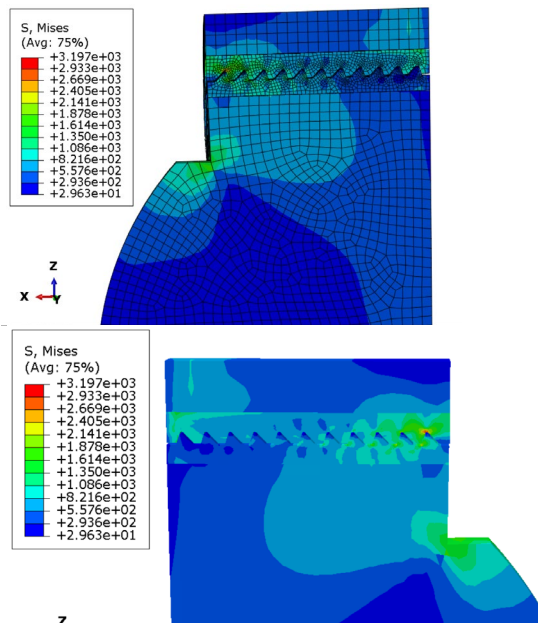


Figure 4: Von Mises stress distribution around the teeth, for the complete three-dimensional model for Case A and Case B respectively.

Case A Results Summary:

The finite element analysis of this barrel and tooth interface (Figure 4, top) shows high von Mises stress concentrations along the meshing region, particularly at the contact edges where the load is transmitted. The stress distribution transitions from the high-stress engagement zone to the lower-stress surrounding structure, suggesting localised force application. The refined mesh in critical areas captures stress variations effectively, though further refinement may enhance resolution. The lower section of the barrel experiences minimal stress, indicating that mechanical forces are primarily concentrated at the tooth interface. The high-stress areas, visible in red and yellow, may

be potential failure points, emphasizing the need for fatigue analysis and possible design modifications to improve durability.

Case B Results Summary:

The finite element analysis results (Figure 4, bottom) indicate significant stress concentrations along the tooth interface, with the highest von Mises stress occurring near the contact edges. The stress distribution transitions from high-intensity regions in the meshing zone to lower-stress areas in the barrel, suggesting localized load transmission. The refined mesh in the critical contact area enhances accuracy, though further refinement could improve stress resolution. The lower barrel region experiences minimal stress, emphasizing that the primary mechanical interaction occurs at the tooth engagement. The high-stress areas, shown in red and yellow, may be potential failure points due to fatigue or wear, warranting further analysis and possible design optimizations to mitigate excessive stress buildup.

CONCLUSIONS

The Finite Element Analysis of the breech block has provided valuable insights into its structural integrity, stress distribution, and deformation under operational loading conditions. The results indicate that the breech block can withstand the applied forces within acceptable safety margins, with critical stress concentrations observed in specific areas that may require further optimization.

The area of significance going forwards is arguably the tooth area in the middle. Using two different boundary conditions, it was observed that the stress is concentrated more in this area. In our future work we want to concentrate future work on material selection, geometric refinements, and potential design modifications that can enhance performance and durability.

Overall, the analysis confirms the breech block's reliability while highlighting areas for improvement to ensure long-term operational efficiency and safety. Further validation through experimental testing is recommended to complement the numerical findings including development of a test rig.

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