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# ENSURING PRECISION FOR SMALL ARMS LOCK ASSEMBLY WITH CONSIDERATION FOR INTERFACE CONTACT STIFFNESS

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rifles, contact stiffness, dimension chain, plastic deformation at part interfaces, Abbott-Firestone curve, finish machining, quenched steel specimens.

ABSTRACT

In small arms manufacturing the lock dimensional chain final link precision is secured with manual file fitting and removing the tolerance intentionally left on the recoil lugs. The manual process reduces the contact stiffness of the lock components, and the final link dimension (between the cylindrical gauge end that simulates a cartridge, and the breeching lock face) set during the assembly is distorted when the breech lock components are exposed to shot impact loads. For this reason, the cylindrical cartridge dummy used for the initial assembly is sized to allow for subsequent plastic deformation at the breech lock component interfaces. The deformation value is determined experimentally on an ad hoc basis. The study shows that the plastic deformation value depends of the force applied to the interface surfaces, and on the loaded contact area. The area, in its turn, depends on the physical and chemical properties of the interface materials and the surface finish (roughness, undulation, geometric shape precision.) Polynomial expressions have been obtained experimentally for the interface plastic deformation vs. relative positioning errors and surface finish relation for parts made of typical military steel grades. To study the relation between the interface surface machining methods and contact stiffness flat specimens, 50RA steel quenched to HRC 40–45 (the roughness $R_Z$ is 10–15 μm) were machined as follows: peripheral pregrinding; flank milling; file crosswise (at 45°) movements. The results and curves generated after processing the measurements made with a HOMMEL TESTER W55 instrument show that finish flank milling yields the best results.

**Introduction. Problem Overview.** Impacts between contact bodies commonly occur in modern machinery. For example, impacts present in rifle and automatic weapon locks. A part's contact stiffness depends on the surface layer properties [1–4]. The lock parts are exposed to high dynamic loads natural for small arms [5]. The loads cause contact deformations at the interface surfaces. For an initial service period as the lock components are exposed to a shot impact loads, plastic contact deformations develop. Finally, they result in the initial assembly accuracy degeneration. This fact shall be considered when selecting the manufacturing process for ensuring the closing dimension accuracy [6–13].

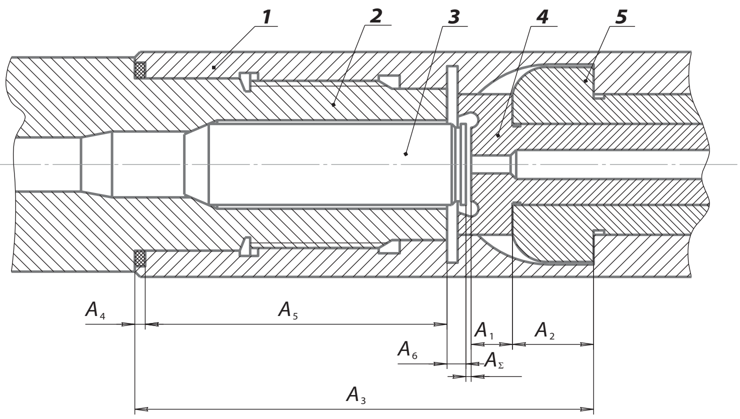



**Fig. 1. A typical assault rifle lock**

**Fig. 1** shows a typical assault rifle lock. The lock reliable operation a paramount for the rifle availability.

The barrel (pos. 2) when assembled to the box (pos. 1) is located off the cylindrical surfaces for assembly. The barrel is fixed in the axial direction by fixing its end face with a predefined thread torque. The lock is an assembly of the bolt head (pos. 4) and the locking lug (pos. 5) with a pair of datum seating surfaces. The lock is located off these surfaces and absorbs most of the shot energy. Initial lock assembly shall ensure a $A_\Sigma$ = 0.05÷1 mm clearance between the lock face (pos. 4) and the go-on gauge dummy (pos. 3) used for the lock assembly and adjustment. The dummy is installed in the barrel chamber (pos. 1.) Since the dimension $A_\Sigma$ is inaccessible and cannot be inspected or measured directly, a set of go-on and o-go gauge dummies have to be used. When a go-on gauge is applied, the clearance shall be $A_\Sigma$ = 0.05÷1 mm. To verify the $A_\Sigma$ < 0.1 mm condition, the no-go gauge is applied. In this case, should the $A_\Sigma$ dimension be incorrect, the lock would not close. As fig. 1 shows, the clearance $A_\Sigma$ between the gauge dummy end (pos. 3) and the lock (pos. 2) is a closing link of the dimensional chain consisting of six dimensions. Dimension $A_6$ itself depends on the combination of the barrel chamber and the gauge dummy dimensions: $A_\Sigma = A_3 - (A_1 + A_2 + A_4 + A_5 + A_6)$.

The required dimensional chain closing link accuracy is secured with manual file fitting and removing the tolerance intentionally left on the lock datum surfaces. The manual process reduces the contact stiffness of the lock components, and the final link dimension (between the cylindrical gauge end that simulates a cartridge, and the lock face) set during the assembly is distorted when the breech lock components are exposed to shot impact loads. For this reason, the cylindrical cartridge dummy used for the initial assembly is sized to allow for subsequent plastic deformation at the breech lock component interfaces. The deformation value is determined experimentally on an ad hoc basis. After acceptance tests, the gauge dummy is replaced with a longer one.

The part interface surfaces are irregular (roughness, undulation, geometric shape Deviations). It significantly reduces the actual contact area compared to the rated one. For this reason, contact deformations prevail in the part motion balance [14], Consequently, contact stiffness and surface geometry are closely related. Contact stiffness depends on the surface deviation height and shape. Roughness numerical properties can be analyzed in different ways. For example, in [15] a part surface layer load bearing capacity is estimated by analyzing the micro deviations: max micro deviation $H_{max}$, micro deviation smoothness height $H_P$; undulation $W_a$, $W_P$, $W_Z$, $S_{mW}$; roughness $R_a$, $R_P$, $R_{max}$, $t_m$, $S_m$, $S$, physical and mechanical surface properties described with microhardness parameters and residual strain $H\mu_0$, $\pm\sigma_0$, $h\mu_0$, $h\sigma_0$.

**Problem Statement.** Summarizing the above, we can assume that identifying the relation between the lock part interface surface plastic deformation value the material's physical and mechanical properties and the surface finish would help find an optimal fitting process. It will facilitate the designer to select appropriate surface layer parameters, while the manufacturing engineer will be able to select optimal machining modes to meet the design requirements.

**Theory.** As a result of machining, part contact surfaces have micro- and macro irregularities. Usually two interface surface initially contact at three points [1, 3, 4, 11]. The strain generated as a normal force is applied to such a part interface greatly exceeds the yield strength because the contact area is so small. Peaks that first come into contact are exposed to plastic deformations (**fig. 2**).

The deformation value depends on the formation of a contact area capable of resisting the load applied to it [14]. It is expressed with an empirical relationship:

$$A_{ri} = \frac{P_i^{\upsilon}}{C[\sigma_T]}, \qquad (1)$$

where $A_{ri}$ is the actual *ith* contact area [mm²], $P_i$ is the load applied to this area [N], $\upsilon$ is the exponent Indicating the force vs. deformation relation (for initial loading $\upsilon = 0.9$),

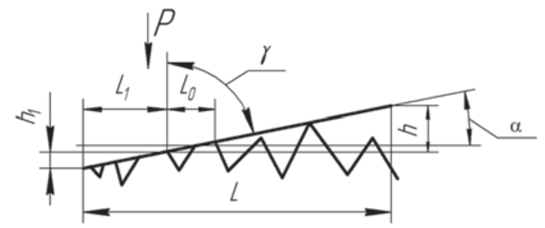



**Fig. 2. Surface profile after applying a normal force**

$[\sigma_T]$ id the material's yield strength [N/mm²], $C$ is the surface layer yield strength enlargement factor.

In terms of physics, the $C$ factor is a relation between the average pressure $p$ applied to the contact area and resulting in plastic yield and the $\sigma_{FS}$ flow stress, i.e. $C = p/\sigma_{FS}$. Note it is in the range $C \approx 2.84$– 4.78 [14]. As a load is re-applied (not exceeding the initial load) without the surface shift, the peaks are elastically deformed. Re-applying a higher load to immovable surfaces (exceeding the initial one) lead to the micro irregularity peak deformation transformation from elastic to plastic. As the load increases, structural changes occur. They change the surface layer's mechanical and physical properties. The yield strength is greatly enhanced. Besides, a higher load results in expanding the plastic deformation area, the actual surface contact area being the sum of the elementary contact areas

$$A = \sum_{i=1}^{n} A_{ri}\,. \qquad (2)$$

A further load increase leads to negligible plastic deformations [15]. Under a subsequent shift-free load the deformed peaks come into contact. Each peak has a certain contact area. If a contact area under initial loading varies directly with the pressure with a proportionality factor value near to 1 ($\upsilon = 0.9$) then under subsequent loadings the value belongs to the $\upsilon = 0.5$–0.88 range [16].

Surface shift prior to each loading results in elastic deformations of the plastically deformed peaks and plastic deformations of the peaks that have not been contacted yet. Under numerous contact surface shifts and repeated loadings more and more peaks are elastically deformed, and less and less are plastically deformed. Multiple load applications cause contact destruction of the plastically deformed contact areas, and irregularity formation.

A dedicated test bed was built to study the Y part approaches in an assembly model. The interface surfaces were filed as it is a common practice for rifle steel processing [1, 3, 11].

The factors were: Ra surface roughness [μm]; HRC is the Rockwell hardness; α° is the part interface expansion angle [degrees]. We hypothesize that the approach distance $Y$ varies with the factors under consideration and can be expressed as the following regression equation:

$$Y = C Ra^{\beta} HRC_{э}^{\gamma} \alpha^{\varphi}, \qquad (3)$$

After logarithmation, it becomes

$$\ln Y = \ln C + \beta \ln Ra + \gamma \ln HRC_{э} + \varphi \ln \alpha\,. \qquad (4)$$

Finally, the experiment result is represented by a polynomial

$$U = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2. \qquad (5)$$

In equation (5) $U = \ln Y$; $x_1$, $x_2$, $x_3$ are coded Ra, HRC, α° factor values. The equation (3) was verified by checking the polynomial (5) linear component validity.

For 30Cr grade steel the factor variation grades are:

$x_1 = (Ra - 1{,}6)/1$; $x_2 = (HRC_э - 42{,}5)/5{,}5$;

$x_3 = (\alpha^\circ - 0{,}13)/0{,}09$.

The experimental model is:

$$U = 10{,}889 + 2{,}8333x_1 - 2{,}6667x_2 + 5{,}2778x_3 + 0{,}3333x_1x_3 + 0{,}94444x_3^2.$$

For 35HGSA grade steel the factor variation grades are:

$x_1 = (Ra - 1{,}6)/1$; $x_2 = (HRC_э - 43)/5$;

$x_3 = (\alpha^\circ - 0{,}13)/0{,}09$.

The experimental model is:

$$U = 10{,}778 + 3x_1 + 2{,}0556x_2 + 5{,}5x_3 + 0{,}25x_1x_2 + 0{,}33333x_1x_3 + 0{,}25x_2x_3 + 0{,}94444x_3^2.$$

For C50E grade steel the factor variation grades are:

$x_1 = (Ra - 2{,}8)/2{,}2$; $x_2 = (HRC_э - 44{,}5)/4{,}5$;

$x_3 = (\alpha^\circ - 0{,}085)/0{,}055$.

The experimental model is:

$$U = 10{,}926 + 3{,}4444x_1 - 3{,}5556x_2 + 3{,}8889x_3 - 0{,}33333x_1x_2 + 0{,}58333x_1x_3 - 1{,}9167x_2x_3 - 0{,}77778x_1^2 + 0{,}55556x_2^2 - 0{,}77778x_3^2.$$

For 30HN2MFA grade steel the factor variation grades are:

$x_1 = (Ra - 2{,}8)/2{,}2$; $x_2 = (HRC_э - 43)/4$;

$x_3 = (\alpha^\circ - 0{,}085)/0{,}055$.

The experimental model is:

$$U = 11 + 4x_1 - 2{,}7222x_2 + 2{,}72222x_3 - 0{,}66667x_1x_2 + 0{,}58333x_1x_3 - 0{,}75x_2x_3 - 1{,}4444x_1^2.$$

The roughness was mostly estimated with profile records within the static sample length *l*. The sample length is such that it is not affected by other irregularities (undulation, micro deviation) [17].

With rough surface profile records, it is possible to estimate a number of micro geometry properties important for the surface load bearing capability assessment. One of them is the bearing surface curve (**fig. 3**).

Let us consider a profile section at a certain distance *p* from the profile peak line. Then the sum of the peak section lengths $\Delta b_i$ at a certain level is called "reference profile length“

$$\eta_p = \sum_1^n \Delta b_i . \quad (6)$$

The reference profile length to the sample length is called “relative reference profile length $t_p$ at the *p* level”. Consequently, the following equation [13, 15] is true:

$$t_p = \frac{\eta_p}{l} = \frac{A_p}{A_c}, \quad (7)$$

where $A_p$ is the rough layer section area(at the *p* level); $A_c$ is the sample surface area.

It follows that the relative reference profile length is equal to the relative rough layer section area at a certain level. A curve expressing the $A_p$ vs. *p* relation is called “bearing surface curve”. It clearly shows the ratio of material in each rough material layer. Such curves were proposed by the US researchers Abbott and Firestone in 1933 [18, 19]. In order for a profile record to represent both longwise and crosswise roughness fluctuations. The record was made at 45° to the machining marks.

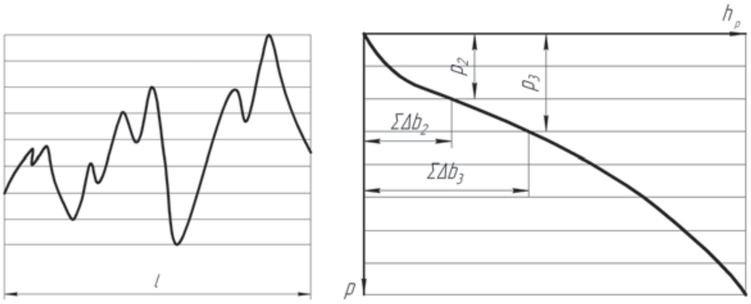
The reference curve can be drawn in relative values. In this case the horizontal axis represents the ration of a cross section are at a given level $A_p$ to a contour area $A_c$, while the vertical axis represents the ration of the approach distance *a* to the max peak height $R_{max}$. The relative material section area at a certain level is $\eta_S$; the relative approach distance is ε.

A contact area equal to the sum of contact patches between individual surface peak pairs is called “actual contact area” [14, 16]. Actual contact patches are grouped at the deformed wave pattern tops creating individual zones that make up the contour contact area. The contour area concept is conventional to some extent. Still, the introduction of this concept enables solving the rough/wave-like surface contact problem. $A_\Sigma$ rough surfaces come into contact, in most cases only the highest peaks do contact. They make up the top of the bearing curve. For contact deformation analysis it is sufficient to consider a part of the bearing surface curve expressed by a simple equation:

$$\eta_S = b\varepsilon^\nu, \quad (7)$$

where $\eta_S$ is the relative cross section area being the ratio of the profile section area sums at the *y* level to the sample length; *y* is the distance measured from a specified baseline; ε is the relative approach of relative section depth expressed as $\varepsilon = y/R_{max}$; *b* and ν are the bearing curve parameters that depend on the machining process; usually $b = 2 \div 4$; $\nu = 1.5 \div 3$.

Papers [20, 21] indicate *b* and ν values for common finishing processes. To study the relation between machining process and part interface contact stiffness/stability in assembly [1, 3, 11] flat specimens made of 50RA steel quenched to HRC 40–45 were used. The surfaces were machined with processes common for assembly manufacturing (the specified roughness $R_Z$ = 10÷15 μm): peripheral pregrinding; flank milling; file crosswise (at 45°) movements.




*a* *b*

**Fig. 3. A profile record (*a*) and the Abbott-Firestone curve (*b*)**

**Specimen surface parameters for various machining processes**

| Transversal roughness | Average parameter value for filing | Average parameter value for finish flank milling | Average parameter value for grinding |
|---|---|---|---|
| *Ra* | 1.81 | 1.165 | 0.576 |
| *Rp* | 7.416 | 5.055 | 2.266 |
| $R_{max}$ | 13.344 | 12.293 | 4.426 |
| $t_m$,% | 51.63 | 53.993 | 49.622 |
| ν | 3.2 | 4.917 | 2.893 |
| *b* | 3.25 | 6.29 | 3.518 |

The surface layer was tested with HOMMEL TESTER W55 from HOMMELWERKE. The profile records were processed, and specific roughness parameters $t_m$; *Rp*; $R_a$; $R_{max}$ were obtained (refer to the **table**.) With these data, and (6) and (7) equations, *b* ν bearing curve parameters were estimated. Their values are also listed.

## Conclusions

1. Operation loads (first shots) change the lock part dimensions due to plastic deformations of the interface surface micro irregularities.

2. The plastic deformation value at the initial break-in is roughly proportional to the load. As the contact area increases, the plastic deformations are reduced, and the dimensions are stabilized.

3. Polynomial relations between the part interface plastic deformations, surface positioning errors and surface quality were identified for commonly used rifle steels.

4. It is proved that the micro irregularity plastic deformation at the interfaces is affected not only by the micro irregularity height, but the finishing process as well. The preferable process is finish flank milling.

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