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PROCEDURES FOR THE PRODUCTION OF GUN PROPELLANTS BY USE OF DIFFERENT EXTRUDERS

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ABSTRACT

This report discusses the use of gun propellants produced by different types of extruders. These extruders are different to each other with respect to their construction, screw configuration and mode of operation.

For the production of propellants by solvent processes, we preferred twin-screw extruders operating either in the synchronous mode or the countercurrent mode. The results of this process consist of extruded strands possessing a high density and an excellent surface, especially for single-base propellants produced by use of the countercurrent operating twin-screw extruder.

The sychronous twin-screw extruder is mainly applied to the processing of triple-base propellants with a high content of nitroguanidine, such as e.g. M 30.

The development of brittleness at low temperature is significantly improved as a result of the manufacturing technique employed.

A planetary roller extruder, a four-screw extruder and a synchronously operating, twin-screw extruder are discussed with reference to the production of gun propellant without the use of solvent. A report is given on the advantages and properties of these extruders as regards optimal plastification of water-wet fibrous NC/NG mix. A method of producing propellant chips, which can be subjected to further processing by the selected extruder or a twin-roll unit, is also described. The ballistic properties of the resulting products are superior to those obtained by standard manufacturing processes.

INTRODUCTION

Gun propellants are nowadays generally produced discontinuously by means of a high-outlay, expensive batch process. A difference is made between gun propellants (GP) manufactured in a solvent process and those that are thermically plastified without solvents. In the solvent process, the raw components are processed into masses via a mixing and kneading process in a trough-type kneading apparatus or also Sigma kneaders; these raw masses are then filled into a hydraulic strand-press

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in batches of 10 to 30 kg (22 - 66 pounds). In a strand-pressing procedure, gun propellant strands (single-hole or multi-hole strands) are obtained, which often cannot cut to the required gun propellant grains until a drying process has taken place. In the case of the cutted grains, this is followed by a costly sieving process, in which excess grains (too large or too small) have to be removed. The subsequent processes such as surface coating vary from one type of gun propellant to the other, a surface coating may even not be necessary at all (Fig. 1).

If gun propellants are manufactured without solvents, i.e. via water-wet fibrous mix (nitrocellulose/nitroglycerin) with various additives such as stabilizers and dibutylphtalate, plastification then takes place between mixing and pressing by using twin rollers (Fig. 1). The processes I have just described have a high personnel and machine outlay. It is also impossible to avoid wide deviations in product quality owing to the methods used, and these have to be equalized in another time-consuming process, i.e. by mixing the individual batches to make up larger units.

It is possible to realize the individual processes, from kneading via pressing to cutting, both with and without solvents by means of a continuous extrusion (in one work process). Apart from a saving in machinery and personnel, extrusion has the advantage, from a technical safety point of view, in that the quantities of explosive material to be processed in the buildings and machines concerned can be kept at a lower level than in the conventional process, without having to make a reduction in capacity.

In different production areas, single-screw as well as multiple-screw extruders can be used, in each case with a fixed geometrical shaft design, principally for the processing of double-base materials.

As these machines are not variable enough for all the different kinds of gun propellant powders on account of the pre-set geometric shaft design, one is often forced to feed the processed materials a number of times through the machines in order to obtain a sufficient degree of plastification. In doing so, the risk is often taken of subjecting a product which is already quite dry and insufficiently plasticized, to a renewed series of mechanical stress - this is not only mechnically but also thermically very problematic.

Operational requirements

Now with a continous process, plus a constant product improvement and with lower-cost processing methods in mind, we studied different extruders which make it possible to manufacture, in a suitable process-length, not only single-base but also multi-base gun propellants, either in a solvent process or in a solvent-less process. It should therefore be possible to process the widest range of different mixtures optimally in one single work process, by making minor changes in screw shape.

The strands leave the extruder head via master shapers. These strands are single-hole as well as multiple-hole perforated, should have such a consistency that they can be cut directly into propellant grains. As far as possible, the high outlay in work time and personnel involved in sieving should be avoided.

Suitable extruders for gun propellants production

A distinction must be drawn between those extruders suitable for a process using solvents and those to be used for plastifying and processing water-wet fibrous mixes (NC/NG mass). We excluded single-screw extruders, as these machines are very sensitive to changes in rheological properties, and then manifest a pulsating behaviour.

We selected the even-speed twin-screw extruder, Model "Continua" by Messrs. Werner & Pfleiderer, and the countercurrent working (reverse-pitched, combing-motion), twin-screw extruder by Messrs. Leistritz, for gun propellants in the solvent process.

For thermic plastification of the NC/NG mass, the "Continua" even speed, twin-screw extruder, after minor modification, and the four-screw evaporator system and the planetary screw were found to be qualified. In the production plant, the disk kneader proved its value.

CONSTRUCTION AND FUNCTION OF DIFFERENT EXTRUDERS

"Continua" even speed, twin-screw extruder

The mixing and kneading extruder "Continua" consists of several screw barrels which can be combined lengthwise, thus making it possible to set up a process line of any desirable length. In addition to this, the "Continua" has the advantage that not only gun propellant in the solvent process but also water-wet NC/NG mass can be plasticized. In this case, however, one of the screw barrels must be constructed so that the water pressed out of the fibrous mix must be able to flow, in the feeder section, backwards and against the flow direction, whereas the product is conveyed downstream towards the extruder head.

The "Continua" is a twin-screw extruder with kneading and mixing facilities, as can be seen in the working principle and the movement of product between the kneading sections (Fig. 2).

The screws are located inside barrels with a "figure-of-eight" shaped bore, which can be heated and cooled. Adaption of the geometrical shape of the screw to the processability of the propellant mass required is in conformance with the fact that the screws (Fig. 3) consist of conveyance and kneading elements which are variable and exchangeable to different configurations.

"Dead spots" above from the saddle or at the screw base are not possible. Thanks to the relevant staggering angle of the kneading elements, e.g. with right staggering angle, the material is conveyded axially downstream, whereas it is partially conveyded backwards with a left staggering angle, this causing a back-pressure.

Countercurrent combing twin-screw extruders

The countercurrent combing twin-screw extruder manufactured by Messrs. Leistritz, also consits of individual screw barrels held together under tension, which can also be arranged to form any required configuration for processing. The bore of the barrels is also in the shape of a "figure-of-eight" in the individual barrels (Fig. 4).

In the countercurrent system, we have screws which are constructed on the lines of box section or bridge section elements, whereby variations of the thread-numbers are possible. 2- and 3-thread screw elements are used by preference, they have variable mounting facilities on screw shafts.

It is possible to install one or more restriction disks (kneading disks). We decided to make use of kneading disks as well as screw elements without profile (Fig. 4) . The degassing section, which is not covered, is used for optical supervision (TV monitor) of the consistency of the propellant mass. Recording facilities of this type provide additional information in the remote control of the system.

Planetary roller extruder

The construction of the planetary roller extruder is shown in the design principle (Fig. 5), shown here once more with a feed-out screw. You can here see milling sections with helical gears arranged in planet fashion around the screw shaft, these are called planetary screws.

The material, filled into a deep-recess filling area, is dehydrated and plastified at the corresponding temperature level between the multiply engaging cog sections of the planetary screw. The helical gear arrangement thus causes in mass to be shifted axially. The pressureless chambers between the planetary screws facilitate efficient degassing.

With the relevant gearing of the main screw and the inner wall of the cylinder (fixed roller barrel), the planetary screws exert a shearing effect (Fig. 5). When the main screw is driven, the planetary screws are forced to turn as well, like the rollers in a roller bearing. The operator also has the possibility of adjusting to the desired friction by determining the number of planetary screws in the system or by planetary screws in different sections and their staggering angle.

For the plastification of NC/NG mass, this type of extruder is admirably suitable. Friction can be adjusted by the number and staggering angle of the planetary screws. There is, however, one problem with the planetary screws from a technical safety point of view, this being where they are located adjacent to a retaining ring. On account of this setback, extensive construction changes are necessary, also with regard to the removal of product and water at the same point, the extruder head.

Four-screw evaporator sytem

The four-screw evaporator system made by Messrs. Werner & Pfleiderer consits of triple arc (3-point) kneading elements (Fig. 6), as opposed to double arc (2-point) kneading elements in the "Continua" model.

These triple arc kneading elements, located in closed casings, are followed by concave section conveyance segments moving in casings with open tops for better evaporation of water present in the NC/NG mass (fibrous mix). Naturally, the length of the process line is greater than the "Continua" system by a number of times. A change in the geometrical dimensioning of the screws is then only possible with difficulty.

Disk kneader

This model is an even-speed, twin-screw extruder with a permanently fixed geometrical screw shape and processing line length, screws and barrel are not variable. The screws themselves consist of individual disk elements, without conveying elements. The "Continua" is nowadays representative for a sophisticatedly designed disk-type kneader.

Manufacturing technology for gun propellants

Single-base gun propellants

For the manufacture of single-base gun propellants which principally consist of nitrocellulose and a stabilizer, the countercurrent, combing type of twin-screw extruder (Messrs. Leistritz) is preferred, with one die restriction and a process length of approximately 25 D (= diameters) is used. The diameter of the screw is 35 mm (1.3779").

The nitrocellulose (NC) in a alcohol wet condition with additives is gravimetrically feed with a differential dosing balance system (Loss in Weight Feeder). Immediately following this, the solvent is sprayed in separately. The extruder is controlled photo-optically with an open degassing section, and continously supervised. The strands leaving the extruder head as single-hole strands and designed for the gun propellants given in Table 1.

The extruded strands of gun propellant are capable of being cut immediately upon leaving the extruder head (shaper). By using a specially designed cutting machine, well-proportioned cuttings are obtained which do not have to be subjected to the conventional sieving process. The subsequent coating process is performed not only single-phase with centralite but also twin-phase with centralite/dibutylphthalate or octylphthalate.

Multiple-hole strands can be produced with exactly the same precision as single-hole strands on this type of extruder. If the geometrical shape of the screws is changed by removal of the kneading disk, it is also possible to manufacture a gun propellant with up to 10 percent DNT by weight.

M 30 gun propellant

To manufacture triple base M 30 gun propellant for the 105 mm caliber, the even-speed, "Continua" kneading and mixing extruder is used. The screws are built up so that kneading blocks with a left staggering angle as well as with a right staggering angle are positioned one after the other, separated by concave section of conveyance elements, on a process line of 21 diameters with a screw diameter of 37 mm (1.4567"). The screw elements in the feeding section may not only consist of concave section elements, but also of box section elements as well.

At the feeding section, alcohol wet nitrocellulose, nitroguanidin and desensitized nitroglycerin is feeded in, including additives. Following this, the solvent is sprayed in and 7-hole strands are produced at a determined torque and pre-set pressure at extruder head. Then the strands immediately being cut to gun propellant grains. It is possible to operate at rotation speeds of 30 to 100 rpm.

The gun propellant obtained, after the drying process, has a grain density as high as the top level in conventionally manufactured M 30, or even higher (Table 2).

Plastification of NC/NG masses

The planetary screw extruder is quite suitable for the plastification of water wet raw powder masses. However, without changes in construction, product discharge and water outlet are at the same point.

The four-screw evaporator shaft system was used for the manufacture of double-base, but it is not flexible enough in its composition of different NC/NG masses. There exists the danger of the water wet fibrous mix being dehydrated but being plasticised to less. The disk kneader is also not variable in the geometrical shap of its screws, so that the raw mass has to pass through the disk kneading process a number of times, but this is not the case with the "Continua".

We thus made our decision in favour of the "Continua" which is here used with a process line length of approx. 14 diameters and approx. 21 diameters.

By using kneading blocks with a left staggering angle, the removal of water by squeezing out of the raw masses (Table 3) as desired, with simultaneous plastification, is achieved. Plastification takes place at temperatures which are also usual in the case of twin rolls. Granulates are obtained with a water content of

0.5 to 1.0 % by weight. This granulate can be processed to strands or, respectively, to carpet rolls used for the manufacture of gun propellants (GP's).

RESULTS

Thanks to using the extruder process, the single base gun propellants has densities situated around 1.65 g/cm^3, whereas in conventionally manufactured propellants this density value is at 1.56 g/cm^3.

For weapon firing, the gun propellant described in Table 4 was used.

In weapon firing ball powder and conventionally manufactured reference propellant (GP) were compared with extruded gun propellants. In the case of the extruded propellants, it can be seen quite clearly that the behaviour as dependent upon temperature is more constant as in the case of the other propellants. This is shown in the instance of the caliber 7.62 (Table 5).

The firing of extruded A 5020 E, also with a smaller surface coating than usual is shown in Table 6.

M 30 gun propellant

Using the "Continua", a M 30 seven-hole gun propellant is manufactured in such a way that this propellant possesses better mechanical properties and also manifests a more favourable brittleness behaviour than a conventionally manufactured GP in batches with trough kneaders.

By analogy to what is termed a "hard ignition", which exerts a sudden pressure on the GP, the brittleness behaviour is dertermined by the transmission of a short-term mechanical compression force to the grains. The stress time, which is within the region of milliseconds, is adhered to in that the compression trial is performed with the propulsion speed of a piston previously determined at 1.5 meters/sec (4 ft 11 in/sec). These trials, in the course of which the compressive strength was measured, are performed with the gun propellant at different temperatures.

As long as the propellant material retains its viscoelastic behaviour, the compressive strength increases as temperature is lowered.

In the diagram illustrating compressive strength as dependant on temperature (Fig. 7), an conventionally manufactured gun propellant powder is shown which has a bad cold brittleness behaviour at a brittle point of - 39 ^{o}C in low-temperature firing from the weapon (- 40 ^{o}C). In the region of - 40 ^{o}C, we have a very rapid rise as well as a very rapid drop in the compressive strength curve. The second curve shows the mechanical behaviour of an extruded M 30. Although the brittle point is at - 33 ^{o}C and we on the other hand are dealing with another compressive strength as well as compressive strength curve, this gun propellant manifests a better mechanical behaviour in the case of firing in the ballistic bomb. Weapon firing has not yet been performed.

For the M 30, a nitrocellulose with a nitrogen content of 12.45 % was used. By means of gel permeation chromatography, the following molecular weight was determinded:

$$\bar{M}_w = 600\ 000$$
$$\bar{M}_N = 100\ 000$$

For M 30 we only used freshly produced nitroguanidin.

Plastification of NC/NG masses (dough)

The plastification of PRM 1 and 3 by means of the kneading and mixing extruders "Continua" clearly produces a high-quality propellant with improved performance. The granules obtained can be processed to strands as well as to carpet sheets with a twin roll.

The linear burning rates are determined at low pressures by means of the Crawford bomb, and at high pressures with the ballistic bomb (Figures 8 and 9).

If the water wet NC/NG masses is given directly on a twin roll, plastified and carpet sheets are produced, the linear burning rate is lower. This therefore means that an increase in performance can be obtained through extruder processing.

FINAL REMARKS

To close, I would like to show you four extruded gun propellants which vary in their geometry (Fig. 10).

The last illustration gives a survey of the control values (Fig. 11).

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TABLE 1 : GUN PROPELLANTS FOR CAL. 7.62 MM X 51 NATO AND 20 MM X 139 DM 48 BW

GP TYPE	A/S 0300 (E)	A 5020 (E)
CALIBER	7.62 X 51 NATO	20 X 139 DM 48
GRAIN LENGTH	1.0	1.7
GRAIN D.	0.64 MM	1.27 MM
NEEDLE DIAM.	0.2 MM	0.2 MM
DENSITY	1.64-1.66 G/CCM	1.65-1.67 G/CCM
SHRINKING	28 %	21 %
SURFACE COATING	CENTRALITE I	CENTRALITE I + DIBUTYLPHTHALATE
EXPLOSION HEAT (JOULE/G)	3670	3520
NC (% N)	13.2	13.2

TABLE 2 : M 30 GUN PROPELLANT FOR 105 MM

GP TYPE	M 30
GRAIN LENGTH (MM)	20
GRAIN D. (MM)	8.4
NEEDLE DIAMETER (MM)	7 X 1.0
DENSITY (G/CCM)	1.68 - 1.70
SHRINKING FACTOR (%)	APPROX. 10
EXPLOSION HEAT (J/G)	4080
NC (%N)	12.45
M	600 000
M	100 000

TABLE 3 : THE CHEMICAL COMPOSITION OF WATER WET FIBROUS NC/NG MIXES (PAM 1 AND PAM 3)

	PAM 1 (WT %)	PAM 3 (WT %)
NC (12.75% N)	52.5	
NC (12.10% N)		37.2
NITROGLYCERIN	43.0	28.7
NITROGUANIDINE		19.6
CENTRALITE I	2.5	
DINITROTOLUENE		4.4
DIPHENTLURETHANE		3.6
METHYLPHENYLURETHANE		2.0
POTASSIUMCRYOLITH	1.0	1.5
OTHER COMPONENTS	1.3	3.0

TABLE 4 : CHEMICAL COMPOSITION OF THE EXTRUDED GUN PROPELLANT A/50300 E AND A5020 E

	WT %	WT %
GP TYPE	A50300 E	A5020 E
NC (13.2 % N)	98.4	98.4
DIPHENYLAMINE	1.0	1.0
SODIUMOXALATE	0.6	0.6
SURFACE COATING	CENTRALITE I	CENTRALITE I / DIBUTYLPHTHALATE
GRAPHITE	0.2	0.2

TABLE 5 : TEST FIRING RESULTS OF DIFFERENT TYPES OF GUN PROPELLANTS FOR CALIBER 7.62 MM X 51 NATO

TYPE	A/S0300	A/S0300 E	K 503
MC (G)	2.8	2.8	2.8
TEMPERATURE (°C)	+ 21	+ 21	+ 21
V (M/S)	830	832	820
P (MPA)	33.20	31.00	32.56
T2 (MS)	0.4	0.4	0.3
TEMPERATURE (°C)	+ 52	+ 52	+ 52
V (M/S)	842	836	850
P (MPA)	38.40	32.60	35.00
T2 (MS)	0.4	0.4	0.3
TEMPERATURE (°C)	- 54	- 54	- 54
V (M/S)	811	800	806
P (MPA)	31.30	29.50	31.40
T2 (MS)	0.4	0.4	0.3

TABLE 6 : RESULTS OF FIRING TRAIL WITH GUN PROPELLANT A 5020 E FOR CALIBER 20MM X 139

GP TYPE	A 5020 E
MC (G)	49
TEMPERATURE (°C)	+ 21
V (M/S)	1028
P (MPA)	36.00
T2 (MS)	1.8
TEMPERATURE (°C)	+ 52
V (M/S)	1049
P (MPA)	39.90
T2 (MS)	1.9
TEMPERATURE (°C)	- 54
V (M/S)	975
P (MPA)	30.10
T2 (MS)	1.9

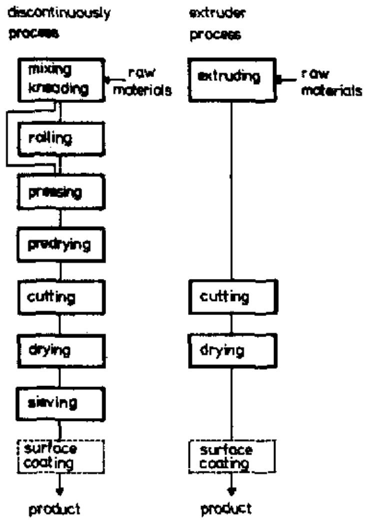

Fig. 1: Processing diagram of the discontinuous process and the extruder process

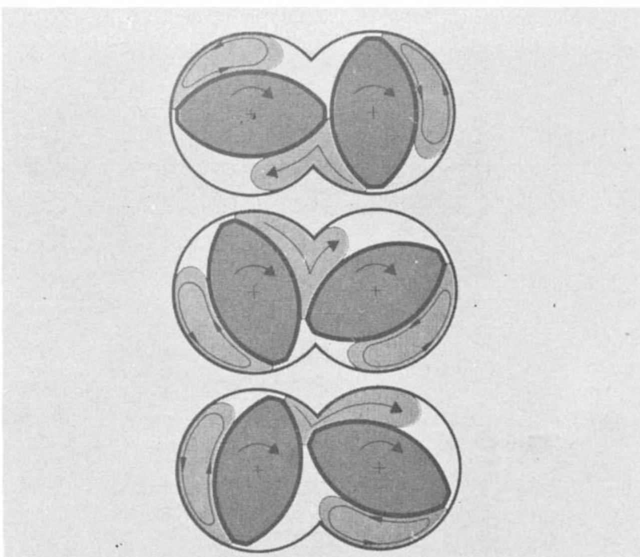

Fig. 2: Movement of material between the "Continua" kneading elements

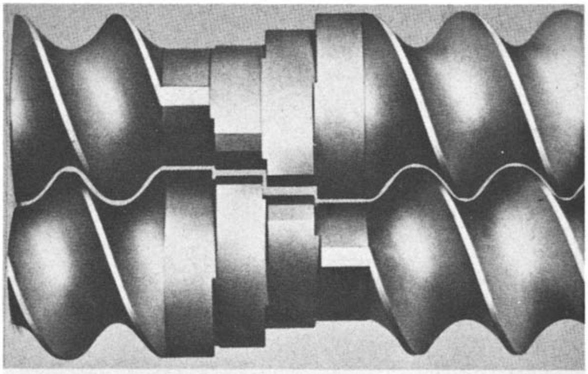

Fig. 3: Sealing profile of the self-cleaning "Continua" screw and kneading elements

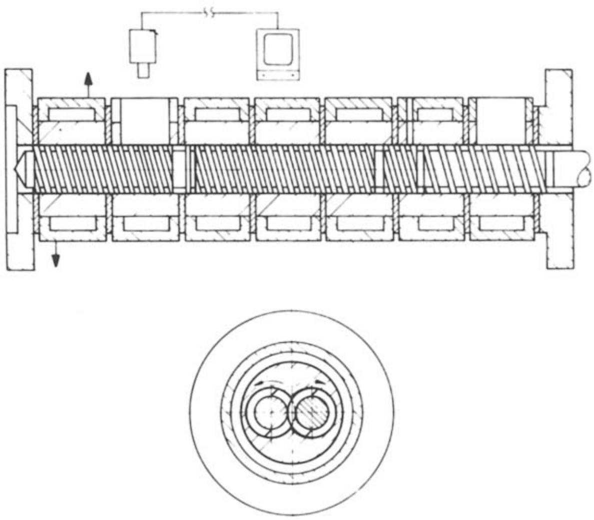

Fig. 4: Design principle of the countercurrent combing/shearing twin-screw extruder

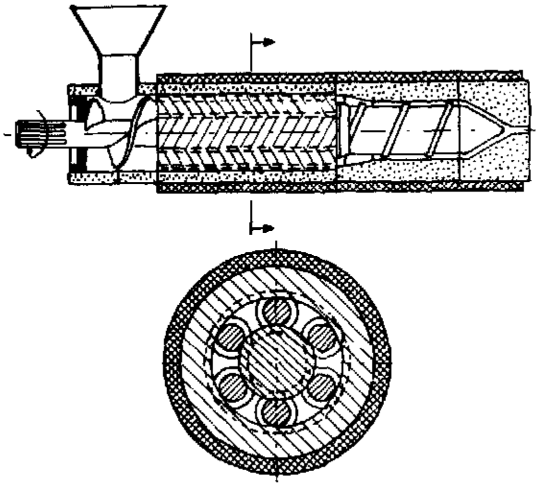

Fig. 5: Design principle of a planetary-screw extruder

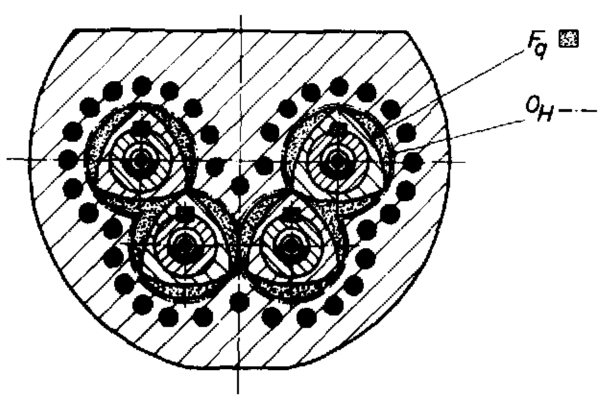

Fig. 6: Design principle (schematic) of the four-shaft evaporator-type helical screw

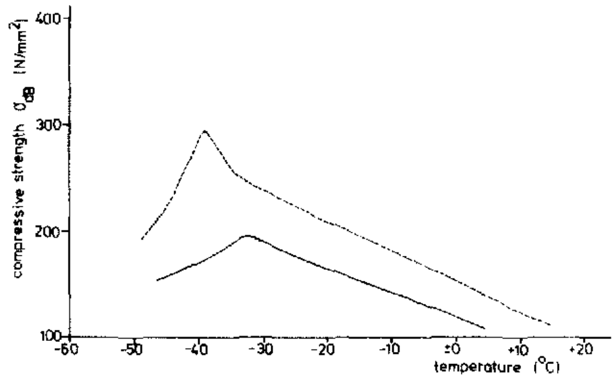

Fig. 7: Compressive strength as dependent upon temperature
-- Conventionally manufactured gun propellant
— Extruded gun propellant

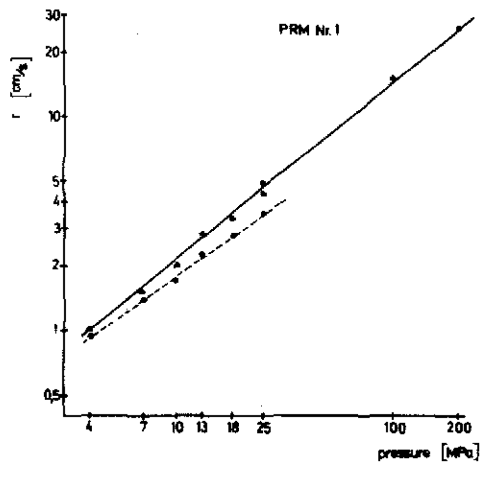

Fig. 8: Linear burning rate as dependent upon pressure

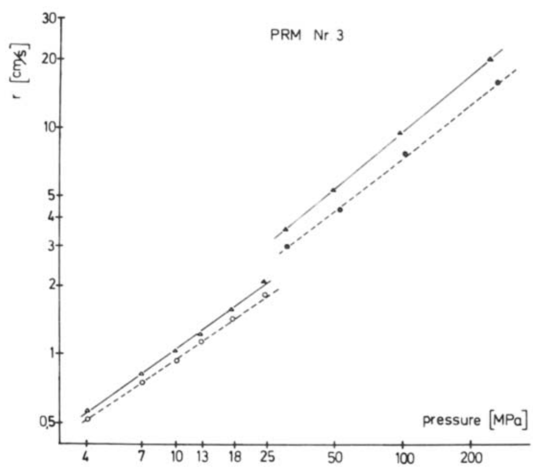

Fig. 9: Linear burning rate as dependent upon pressure

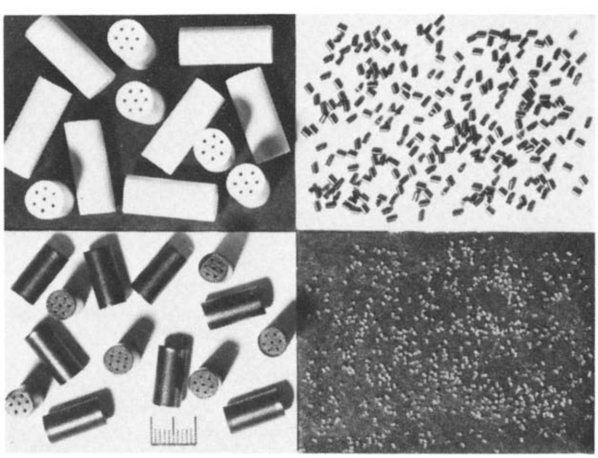

Fig. 10: Extruded gun propellants with their different geometrical shapes

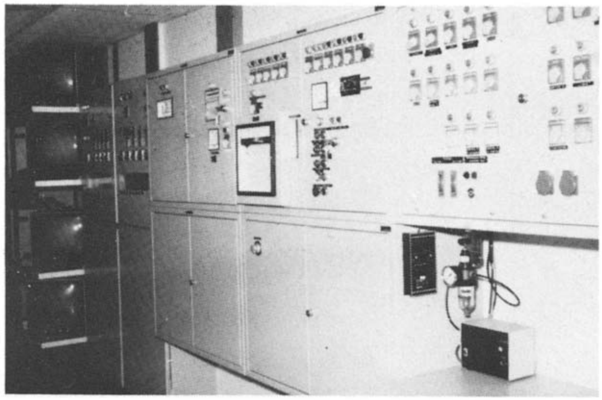

Fig. 11: Survey (photograph) of the measurement and control station