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SOME ASPECTS FOR DESIGNING MACHINES FOR GRAIN HARVESTING [1/]

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Some Aspects of Designing of Grain Harvesting Machines

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1. Area Under Crops and Yields of Major Grain Crops

The harvesting of grain crops completes the whole process of grain production. The amount, quality and cost of the product are dependent in the final analysis on harvesting efficiency.

Depending on the variety of crop, the agrotechnics of cultivation and climatic, weather and other conditions, the physical and mechanical properties and the yields of crops harvested vary over a wide range, which imposes stringent requirements upon grain harvesting machines.

The most popular agricultural crops in developing countries, like in all other countries around the world, are wheat, barley, corn, millet and sorghums and rice. Table 1 indicates cultivated areas and the average yields of grain crops for 1966 in some of the developing countries of Africa, Asia, in Africa and Latin America as a whole, and also, for comparison, in certain well developed countries. The areas under major grain crops in developing

Table 1. Area Under Major Grain Crops and Yields of Gra [illegible] ops for 1966

Source: FAO, Production Yearbook, 1966 ([illegible])

Country	Wheat		Rye		Barley		Oats		Corn		Millet and sorghum		Rice	
	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per ha	in thous. ha	cent-ners per h
Algeria	1,475	4.3	-	-	391	3.5	19	3.5	3	12.0	1	7.1	2	28.
Ethiopia	432	7.3	-	-	988	8.3	-	-	777	9.5	4,799	6.5	-	-
Kenya	122	10.4	-	-	10	14.0	5	2.1	59	9.3	-	-	3	49.
Libia	180	2.2	-	-	400	2.5	-	-	6	2.0	2	10.0	-	-
Maly	3	13.3	-	-	-	-	-	-	60	11.7	1,200	7.7	194	10.
Morocco	1,635	5.0	2	3.3	1,775	2.8	22	5.5	438	3.5	6	3.8	4	60.
Sudan	57	12.0	-	-	-	-	-	-	18	6.1	1,889	6.0	-	-
UAR	605	26.8	-	-	42	24.0	-	-	661	35.7	220	39.2	468	41.
Africa	5,705	5.3	23	3.9	3,606	4.5	276	4.7	14,869	9.8	29,599	6.4	2,844	13.
Latin America	8,258	12.6	458	6.6	1,308	9.9	688	11.6	24,596	13.1	2,374	18.4	5,499	16.
Pakistan	5,276	7.5	-	-	176	5.4	-	-	551	10.6	1,396	4.6	10,480	15.
Iran	4,200	7.6	-	-	1,200	8.3	-	-	17	8.8	17	10.6	375	23.
Irak	1,737	4.8	-	-	1,169	7.1	-	-	3	14.9	15	11.1	141	22.
India	12,656	8.2	-	-	2,633	9.0	-	-	5,061	9.9	37,554	4.5	35,598	12.
Afghanistan	2,345	8.7	-	-	-	-	-	-	505	14.3	-	-	220	15.
Burma	152	6.4	-	-	-	-	-	-	143	4.2	145	2.8	4,516	14.
USA	20,180	17.7	516	13.7	4,130	20.7	7,228	16.1	23,040	45.4	5,185	35.0	796	48.5
Canada	12,016	18.7	294	14.9	3,019	21.9	3,207	18.0	326	51.7	-	-	-	-
Denmark	94	41.6	46	29.4	1,112	37.4	234	37.0	-	-	-	-	-	-
Italy	4,274	22.0	46	17.9	179	14.1	359	13.3	988	35.5	6	35.5	132	46.
USSR	69,958	14.4	13,583	9.7	19,396	14.4	7,162	12.8	3,229	26.1	3,299	9.9	248	28.7

countries range from 200,000 hectares (Kenya) up to 93.5 million hectares(India); in all the countries of Africa and Latin America the figures are 57 and 42 million hectares, respectively. The average yield of these crops also varies over wide ranges: wheat from 2.2 (Libia) to 26.8 centners per hectare (UAR); corn from 2(Libia) to 44.2 centners per hectare (Zambia); millet and sorghums from 3.8 (Morocco) to 39.2 centners per hectare (UAR), and rice from 8.4 (the Sudan) up to 60 centners per hectare (Morocco).

The grain crops presented in Table 1 occupy (percent of the whole area under each major crop):

(1) in the countries of Africa: millet and sorghum 52 percent; corn 26 percent; wheat 10 percent; barley 6.4 percent; and rice 5 percent;

(2) in the countries of Latin America: corn 57 percent; wheat 19 percent; rice 12.7 percent; millet and sorghum 5.5 percent; barley 3 percent; oats 1.6 percent; and rye 1 percent;

(3) in the countries of South Asia (Pakistan, India, Afghanistan, Burma): rice 42 percent; millet and sorghum 33.5 percent (mainly in India and Pakistan); wheat 17 percent; corn 5.2 percent; and barley 2.3 percent;

(4) in the countries of Near East (Iran, Irak): wheat 67 percent; barley 26.7 percent; rice 5.8 percent; millet and sorgum 0.3 percent; and corn 0.2 percent;

(5) in the USA: corn 37.8 percent; wheat 33 percent; oats 11.8 percent; millet and sorghum 8.5 percent; barley 6.8 percent; rice 1.3 percent; and rye 0.8 percent;

(6) in Canada: wheat 63.7 percent; oats 17 percent; barley 16 percent; corn 1.7 percent; and rye 1.6 percent;

(7) in Denmark, barley 74.8 percent; oats 15.8 percent; wheat 6.3 percent; and rye 3.1 percent;

(8) in the USSR: wheat 60 percent; barley 16.5 percent; rye 11.6 percent; oats 6.1 percent; corn 2.8 percent; millet and sorghum 2.8 percent; and rice 0.2 percent.

In the countries of western Europe, due to the high level of the agrotechnics of culivation and also to the favourable climatic conditions, not only the highest yield of grain crips is obtained, but the stability of yields from year to year as well as with respect to crop varieties is also observed (for instance, in Denmark, 37 to 42 centners per hectare, and even the yield per hectare of rye is 30 centners).

In the USSR, owing to an exceptionally large variety of soil and climatic conditions, the yields of grain crops vary over wide ranges.

For example, in 1967 the average yield in the Ukraine was: wheat 23 centners per hectare, and millet and sorghum 14 centners per hectare; in Kazakhstan: wheat 6.3 centners per hectare, and millet and sorghum 4.2 centners per hectare. In the Kuban region, the average yield per hectare of wheat is higher than 30 centners, and the figure on many farms reaches 40-50 centners.

Under the conditions of the arid steppes in Kazakhstan (the regions of virgin land now being cultivated and called "Tselinnye zemly") the deficiency of water limits the possibility of increasing crop yields and makes the application of fertilizers ineffective; however, under these adverse conditions the Research Institute of Grain Farming in Shortandy (the Tselinograd region) succeeded in obtaining the average wheat yield of 15 to 17 centners per hectare over tens of thousands of hectares every year. Such an increase in the yield of wheat has been achieved by the proper use of new techniques and special machines for erosion control, mechanical cultivation of soil by means of a subsurface cultivator without turnover of sod, and by the use of trash or mulch cover and other agrotechnical means for preservation of water in soil and for control of both wind and water ersion.

In undertaking these measures the Shortandy institute took into consideration the experience of many years of soil treatment in the rid regions of Canada, and revised it creatively for adap ation to the particular conditions of the virgin nds of Kazakhstan.

In many de eloping countries the grain crops are cultivated der the conditions of arid climate. The experien e gained in Canada and in the Soviet Union in increasing crop yields and combating soil erosion under similar conditions should be utilized to the best advantage in these countries.

2. Methods of Grain Harvesting

Two principal methods for harvesting grain crops are distinguished: the windrow or multistage method (mowing and binding with subsequent threshing) and the combine harvesting providing for direct or single-stage combining and windrow or two-stage combining.

In the countries of western Europe, North America and in some other countries the windrow method of grain harvesting using binders and stationary threshers was predominating for many years. The availability of a large number of such machines on farms and also the small size of most farms have been and still are a considerable obstacle to the wide employment of combines in these countries.

In 1930s, for a comparatively short period of time, the Soviet Union completed the change-over from hand harvesting and the use of simple machines (horse-drawn reapers and threshers and hand winnowers) to the most progressive method--the use of combine harvesters, by means of which more than 98 percent of all grain crops, groats, oil-producing crops, podded legumes and grasses for seed are harvested today.

The combine harvesting of these agricultural products has become the principal method all over the world and is now firmly replacing all other methods. In comparison with the windrow (multistage) method the combine-harvester direct method has indisputable advantages as regards all the indices (losses, labour expenditure, cost of production, etc.). However, in complicated and varied harvesting conditions, especially in the USSR with its sharp differences in the climate, weather and other regional peculiarities, the application of the direct combine harvesting introduced new serious problems. These problems necessitate the corresponding improvement of grain harvesting equipment to meet the requirements under the conditions of a particular region.

The properties of crops harvested vary over very wide ranges, depending on the species, variety, zone of cultivation, weather during the vegetative stage and the period of harvesting operations and even during each day of harvesting. In many cases--in areas of increased moistening, in harvesting rice, etc.--additional difficulties are encountered due to the necessity of providing the movement of machines along water-logged soil with a low bearing capacity.

The above-mentioned difficulties which arise from the combine harvesting of grain crops and the high strain of field operations caused by the necessity to garner the full yield of grains and straw for a short period of time led many specialists to search for other noncombine methods of harvesting.

In the USSR, three noncombine methods have been developed and tested. These methods provide for delivery to the station and processing, under stationary conditions, of bulk cereal crop in whole or ground form, or of uncleanded grain.

In GDR, similar work was carried out by using silage combines for mowing and grinding grain crops and subsequently processing bulk grain at the station.

This harvesting technology has been developed at a higher level in Czechoslovakia, where a system of machines was designed for cutting, delivering to the station and processing bulk grain under stationary conditions (batch-loader and thresher-precleaner with pneumatic discharge of choppedstraw). The Czechoslovakian specialists do not oppose this method to the combine harvesting, but they consider it expedient to apply it in those regions, where the grain crop are planted on steep slopes.

Repeated testing of "noncombine" methods of grain harvesting has demonstrated that no advantages are gained from the use of these methods as compared with the combine method, and moreover, contrary to the expectations of the advocates of noncombine techniques, big complications arise in their realization. What is contemplated in this noncombine technology, in lieu of the combine, is a cumbersome system of machines which limit the capacity of each other.

Additional difficulties appeared in connection with the necessity to provide the uniform feeding of dense (nonloose) straw heap with a variable amount of grain to the stationary machines. The combine takes advantage of the natural uniformity of distribution of the standing crop over the field, whereas in "noncombine" methods it is made use of only in cutting and crushing operations with partial or complete threshing, and the most formidable operation--separation of grain from straw--is to be performed after collection of the crushed bulk grain in a pile, which involves violation of the grain-to-straw ratio in various potrions of the pile.

Investigations into "noncombine" methods of grain harvesting are still in progress in the USSR and Czechoslovakia, but at the present time there are no grounds to hope for the success of this technology. Even in conditions of rugged terrain with steep slopes (up to 20-22^{0}) this technique is hardly capable of offering advantages over the hillside combine.

All the experience accumulated up to the present time indicates that the perspective in the development of grain harvesting techniques is in the wide application and continuous improvement of the combine harvesting method, and the developing countries should take up the use of the most perfect and productive combines.

The harvesting conditions in the regions of the USSR with differences in the climate resemble in many respects those in developing countries (regions of insufficient and excess moistening; dry and irrigation farming; crop varieties being cultivated, and variations in crop yields, etc. and the experience in the use of combines under these conditions can be put in practice to the best advantage in these countries.

In the USSR, before 1955 use was made of the direct (single-stage) combining, and later the windrow (two-stage) method won remarkably rapid acceptance and found wide usage. In major grain-producing regions up to 70 percent and even more of the crop is picked up by the windrow method.

In recent years there has been observed a tendency to achieve a rational combination of the direct and windrow methods.

On the one hand, the windrow combining involves an additional operation, that of windrowing, which entails corresponding expenses, and on the other hand, it permits the harvesting operations to be started at an earlier time, taking advantage of the period of gold ripeness of grain; prevention of crop overmature and harvesting with lower losses. In order to avoid considerable losses from the shaking of grain from the stalks by wind it is necessary to pick up the grain when it is fully ripe within 4 or 5 days, but the direct combining would require a considerably greater number of combines, trucks and grain-handling equipment. Use of the windrow combining over 50 percent of the land under grain cr/op provides a two-fold reduction of the required number of these machines, though at the expense of use of an additional number of much simpler and less expensive machines— windrowers.

Besides, the windrow or two-phase harvesting is of advantage for picking up weedy crops. The wetted weeds in windrows have time to dry and do not exert an adverse influence on the operation of the combine.

The windrow method should also be applied in the areas subject to strong wind and the falling of hail at the harvest time. In these conditions the stalks lose a large amount of grain and even run the risk of being destroyed, but in windrows they are preserved.

3. Basic Requirements Imposed on Grain Harvesting Combines and Ways of Raising Technical Level

The modern grain harvesting combine must meet very high requirements as to capacity, operational reliability, reduction of losses and damage of grain and of the maintenance and adjustment time, improvement of working conditions of combine drivers, possibility of harvesting of various crop varieties, operation under varied conditions, aesthetic appearance, etc.

The capacity of the combine depends on numerous factors: the throughput of a threshing device, distribution of bulk grain over the field and the condition of the field, conformity of the operating width of cutterbar with the yield and the charging of threshing device, qualification of the driver, organization of the transport facilities for unloading the grain, the design of the combine and its operation (breakages, clogging, etc.) and so on.

The capacity of the threshing device of the combine (the permissible feeding of bulk grain in kg/sec, reduced to the accepted ratio of grain to straw, with the proper functioning being provided) depends, in its turn, upon a number of factors, including the scheme of operation, the size (width and length) of the grain separating-and-threshing unit, and the properties and condition of the crop being picked up.

The harvesting conditions prevailing in developing countries (tropical climate, wide variations in yield, etc.)

place further requirements, which must be considered in the designing of combines intended for use in these countries.

Today, ever increasing use is being made of sealed-for-life bearings and also of devices for rapid adjustment of working elements, this permitting a sharp reduction of the maintenance and adjustment time.

Considerable work is being carried on to improve the working conditions of combine drivers.

All-weather (airtight) and air-conditioned cabs are now bein developed, the steering effort is reduced, drivers' seats with an improved cushioning frame are introduced, which are adjustable to the weight and height of a driver, and control of the principal working elements of the combine is made much easier.

Serious attention has recently been paid to the aesthetic appearance of combines; besides seeking to modernize the combine in its external appearance, the designers do their best to provide better safety, protect V-belt and other transmissions against the detrimental effects of atmospheric precipitation and sunlight, reduce vibrations and noise, and to create better working conditions for the combine driver.

Many firms with a long-established production of grain harvesting combines try to introduce refinements into the external appearance of their combines with minimum expenses, and without reconstruction of production and substantial modification of working elements that accomplish the technological process.

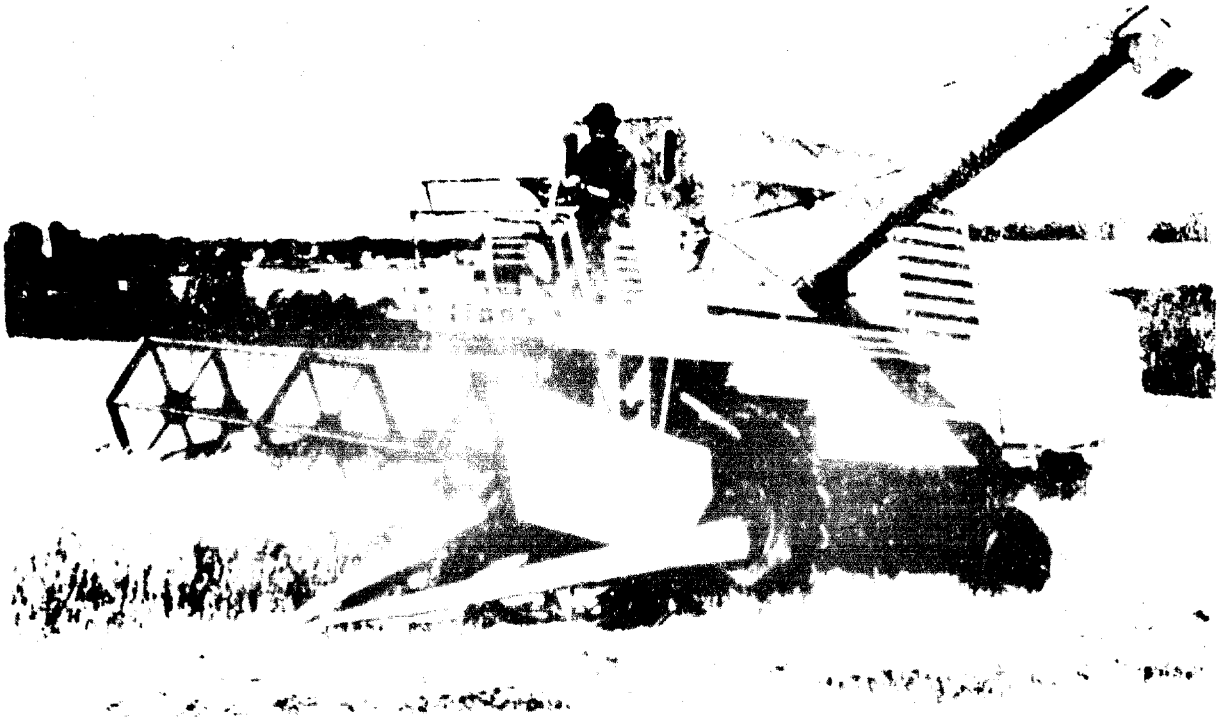


Fig. 1. Combine harvester "Senator", Claas, GFR.

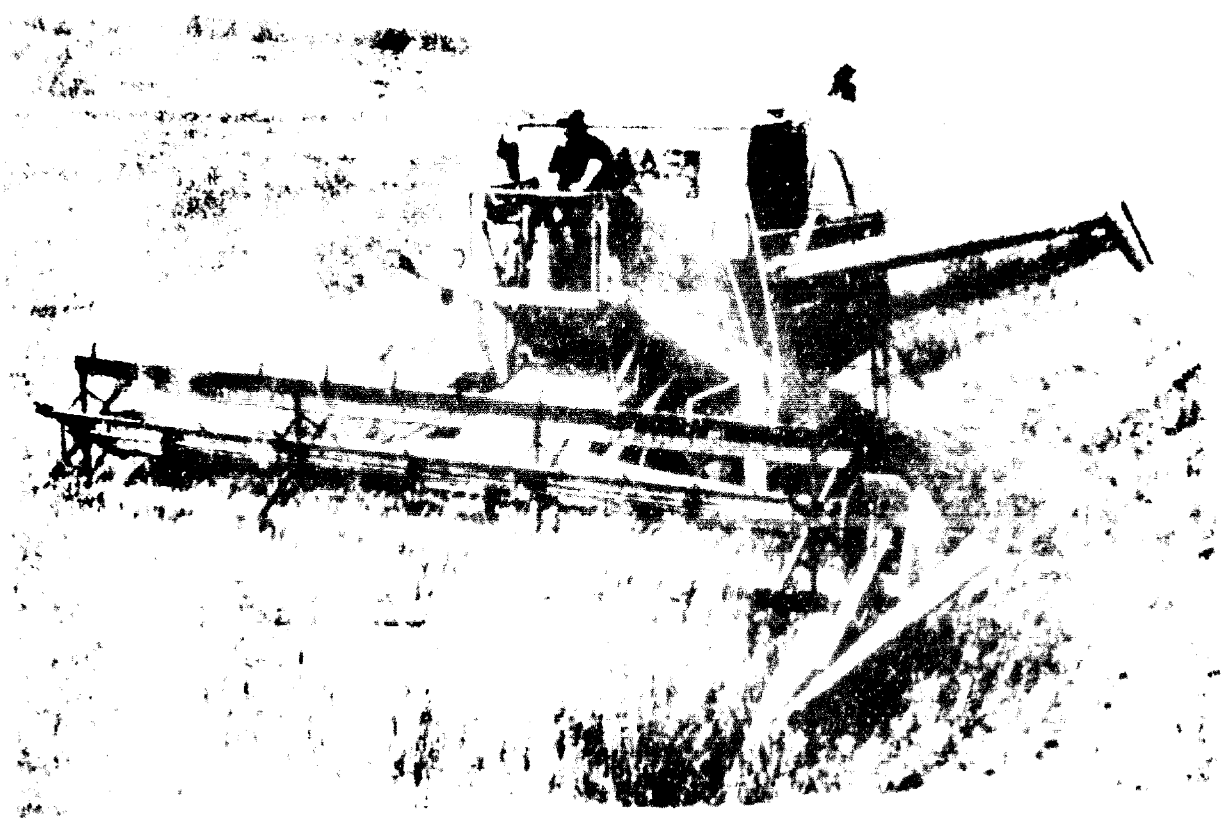


Fig. 2. Combine harvester "Matador Gigant", Claas, GFR.

For example, the Claas firm in German Federal Republic switched to the production of a new combine "Senator" (Fig. 1) which differs only in external appearance from the earlier produced combine "Matador Gigant" (Fig. 2). Other combines put out by this firm underwent similar changes in their appearance.

The B.M., VOLVO, in Sweden made a shift to the production of a new combine harvester "S-950" (Fig. 3) without substantially altering the working elements and size of the previously produced combine "S-1000"(Fig. 4), with the exception that the new model was given a modern appearance.

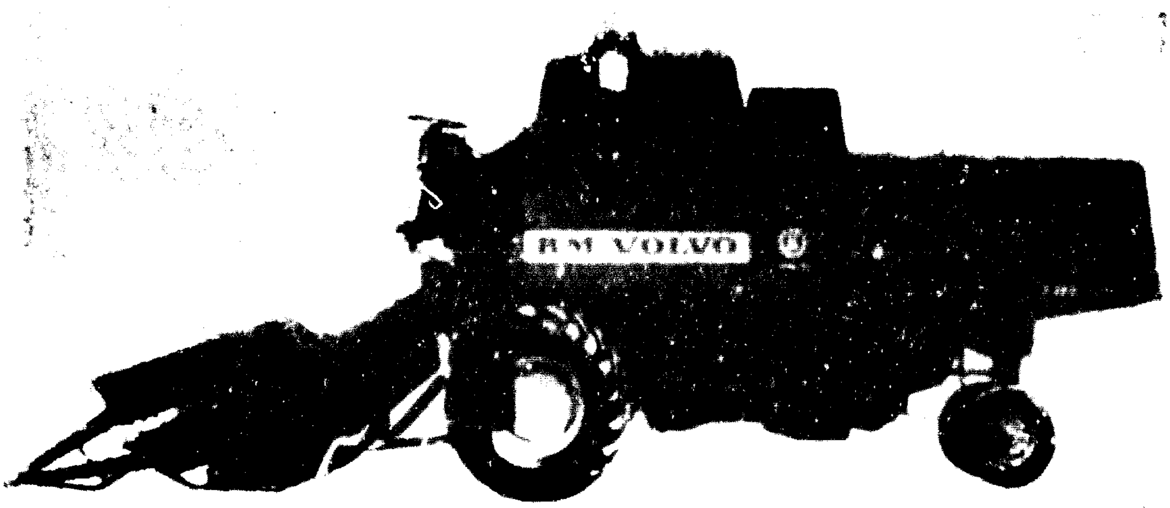


Fig. 3. Combine harvester "S-950", B.M. VOLVO, Sweden.

In the USSR, a set of experimental models of grain harvesting combines "Niva" (Fig. 5) and "Kolos" (Fig. 6) have been put out by the industry, which have modern external forms and are built in versions with one or two threshing drums. A number of refinements have been introduced into these combines to meet the requirements indicated above.

The combine harvester "Niva" is equipped with a threshing device of the same basic dimensions as the combine "SK-4" and a 4-section straw rack. Its width is 1200 mm. The driver's cab is located on the left side and has a good view of the edge of the field over which the operator drives the combine. Behind the cab is a platform from which the driver has easy access to the engine and can come down to the ground using a convenient flight of stairs.

In the combine harvester "Kolos" the driver's cab is situated between the two sections of the hopper and has an exit for the operator to get to the engine located at the rear of the cab. The width of the threshing device is 1500 mm, and the straw rack is of the 4-section type.

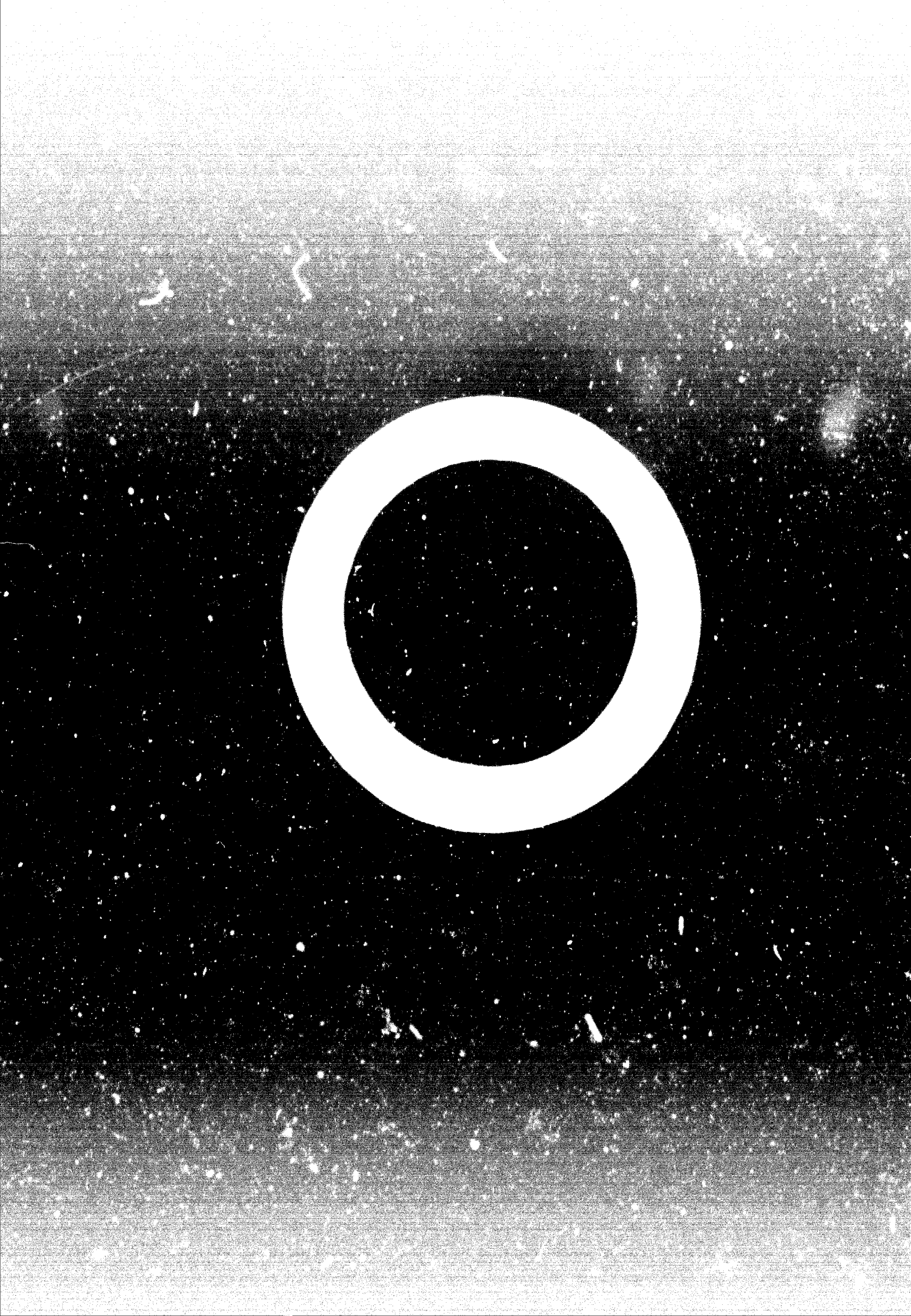
In these both combine harvesters the hopper has a capacity of up to $3m^3$, and the driver can switch off the reaping device with the combine running, change the clearances between the drums and the concave and control the principal operating units of the machine. The sections of the straw rack are mounted on sealed-for-life bearings.

The automatic control of the speed of travel of the

Fig. 4. Combine harvester "S-1000", B.M., VOLVO, Sweden.

Fig. 5. Combine harvester "Niva", USSR.

Fig. 6. Combine Harvester "Kolos", USSR



combine harvester over the field, depending on the variation of the yield, to provide constant feeding, is now entering the production stage.

The results of the laboratory and comparative field tests of the combine harvesters built in the USSR and elsewhere have made it possible to improve the design of "Niva", "Kolos", and other combines which are now produced in the USSR (SK-4A, Rostov Comine Factory, and SKD-5 "Sibiryak", Krasnoyarsk Combine Factory), as a result of which the capacity of these combines was increased by 30-40%.

Results of Laboratory and Comparative Field Tests of Combine Harvesters

Considerable work has been carried out in the USSR on investigation and development of combine harvesters with a two-drum threshing-and-separating device. The founder of [illegible]ence of agricultural machinery Academician [illegible].P. Goryachkin in 1934 suggested an idea of the advantages of a two-drum threshing-and-separating device. He maintained that the first drum, operating under mild conditions (reduced speed and increased concave clearance), threshes the greater proportion of the most valuable, fully ripened grain without damaging it while the second drum, operating under severe conditions, shells the remaining, smaller part of the less valuable grain strongly hold in the stalks. As a result, the total damage of the grain being threshed is less and losses from returns are lower.

More than 15 years ago the two-drum threshing-and-separating unit was mounted on combines intended for harvesting rice; in front of the conventional beater drum was placed a peg-tooth drum (Fig. 7).

Later the Krasnoyarsk factory built experimental models of grain harvesting combines with two beater drums mounted side by side. Laboratory and fields tests showed, however, that the large proportion of the grain that had been threshed but had no time to separate in the first drum, was hit by the counter rotating second drum and damaged. This forced the designers to place an intermediate

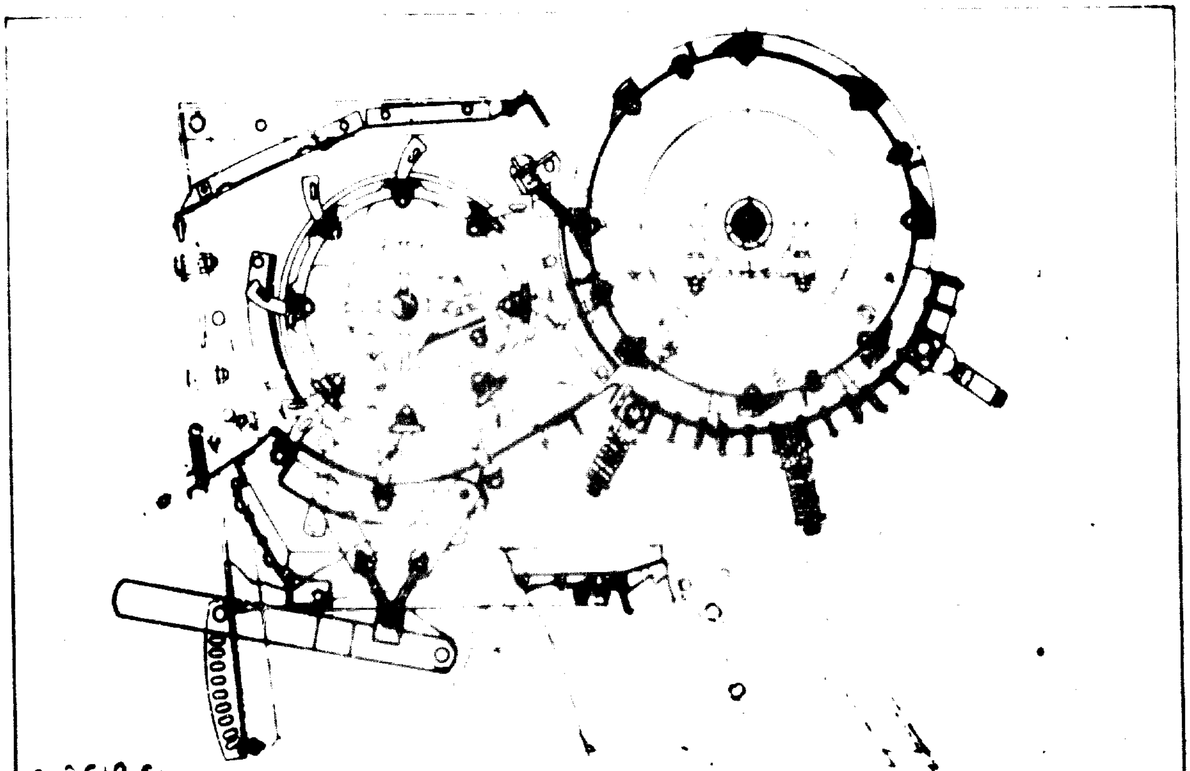


Fig. 7. Diagram of combine for harvesting rice.
Thresher unit.

beater between these drums (Fig. 8), as a result of which the extent of grain damage was reduced.

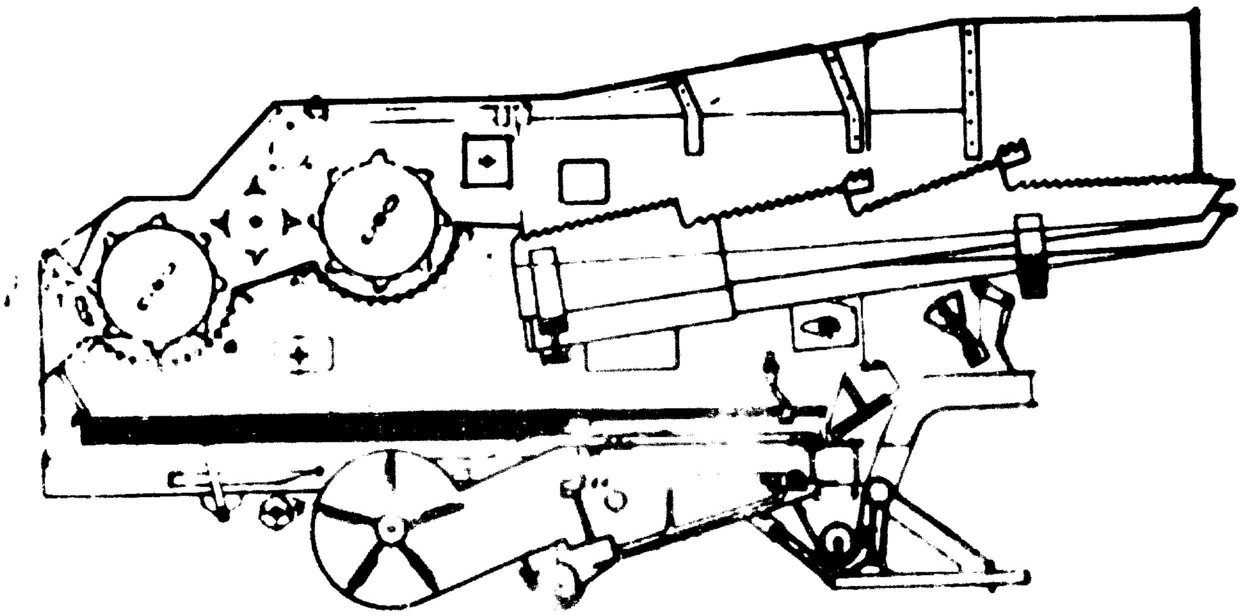


Fig. [illegible] of thresh[illegible] [illegible]mbine harvester [illegible]-5 (CKA -5) "S[illegible]".

Very good results are attained by the use of an intermediate beater with back rotation, a reversing beater (Fig. 9). In this case there is no counter impact when the beater catches the heap and feeds it to the second drum, because in both cases the speeds of the heap and beater blades or the bars of the second drum are subtracted from each other rather than added.

The use of two drums, especially with a reversing intermediate beater added, makes it possible not only to reduce grain damage, but also to increase considerably the separation efficiency. From the upper part of the reversing beater the heap is fed to the second drum tangentially to its circumference in a thin layer at a speed of 15-18 m/sec, the kinetic energy of the grain being used up in passing through the concave grate."

The tests demonstrated that at a feed rate of about 5 kg/sec of bulk grain in a one-drum threshing-and-separating unit the efficiency of separation (through the concave grate) is 80-85 percent of grain, whereas in a two-drum unit the separation reaches 95-97 percent with only 3-5 percent going to the straw rack.

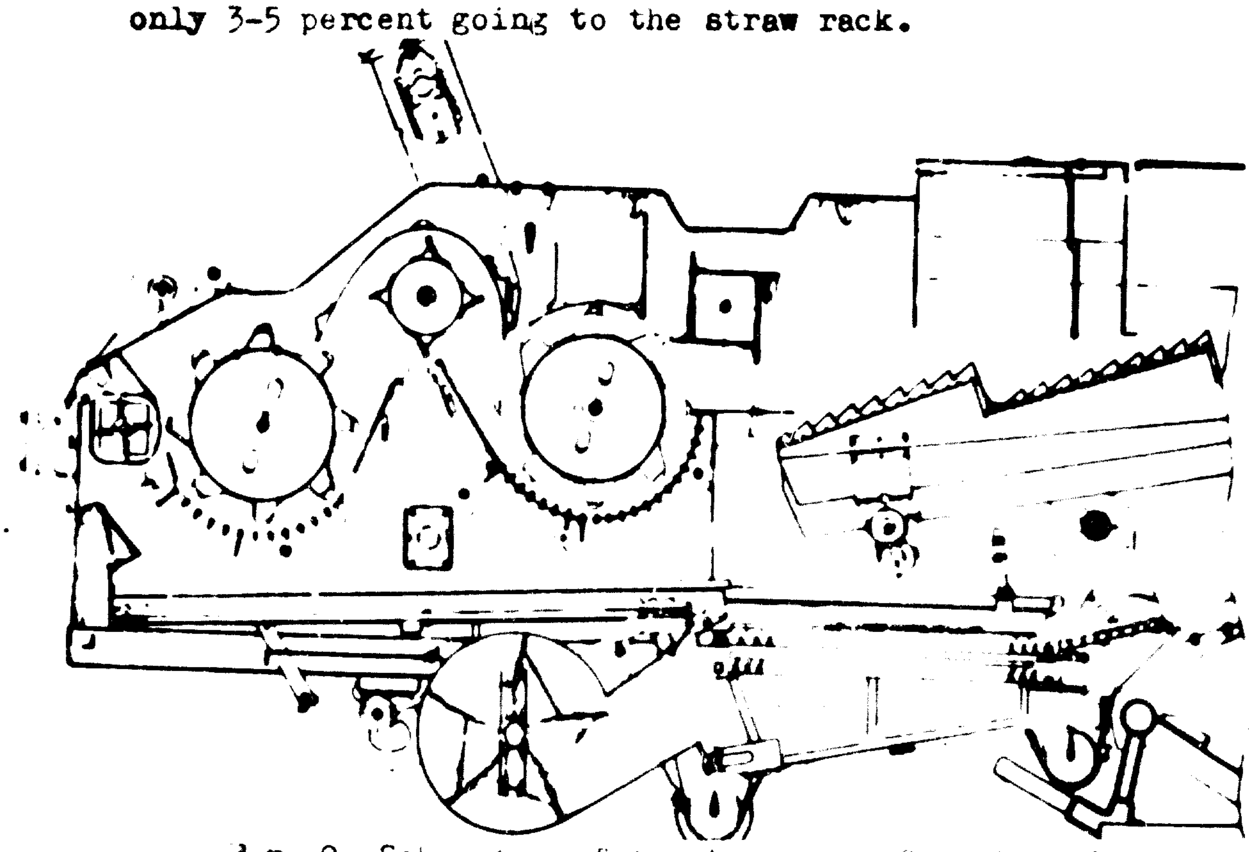


Fig. 9. Schematic of the thresher of combine harvester SKPR-5 (СКПР-5) "Niva".

The direction of feed of the heap from the beater to the straw rack is also very important. Formerly in all combine harvesters, and even today in the majority of them the heap from the drum passes below the beater axis and is thrown upward by its blades (or spike-teeth) to the cover or inclined shield (Fig. 10), and when striking against the cover the heap loses its velocity. Here the kinetic energy of the grain is used for passing through to the top layers of the heap, and on the straw rack the grain has to go down through the entire thickness of the heap, which hampers separation and increases grain losses.

Now the trend in the designing of combine harvesters is to direct the heap from the drum vertically upward to the other side of the beater axis toward its blades which

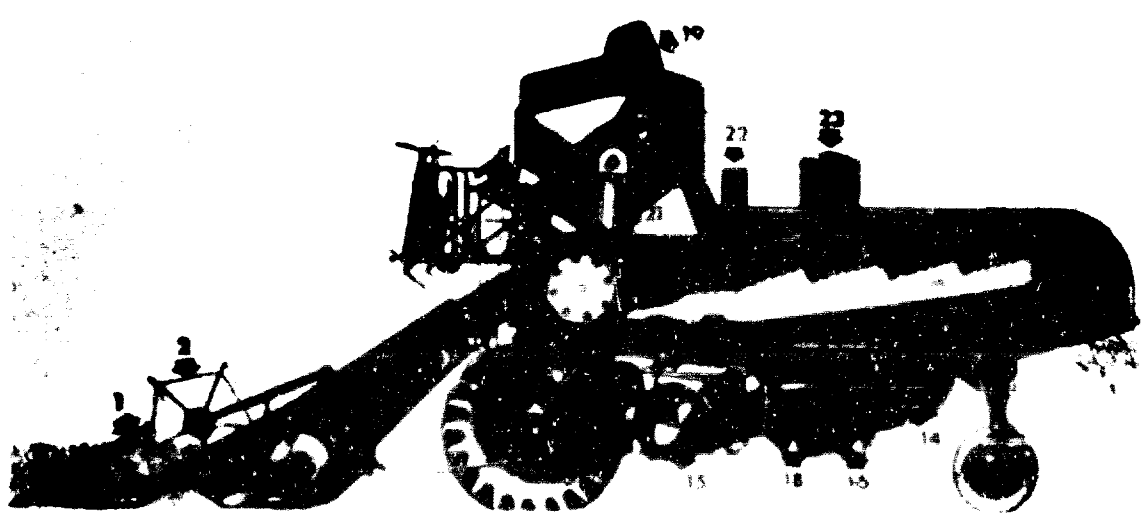


Fig. 10. Schematic of combine harvester "L-1000" B.M. VOLVO, Sweden.

moving counter to the heap throw it onto the beginning of the strawwalkers. The heap is then moved across the strawrack lower at an acute angle. With this direction of the heap the kinetic energy of the grain is expended in passing through to the lower part of the layer, closer to the walker surface, which speeds up considerably the separation and reduces losses of grain in the straw.

Figure 11 is a graph plotted on the basis of the research work carried out in the laboratory of the All-Union Research Institute of Agricultural Machine Building, USSR. Three varieties of wheat were used for these investigations.

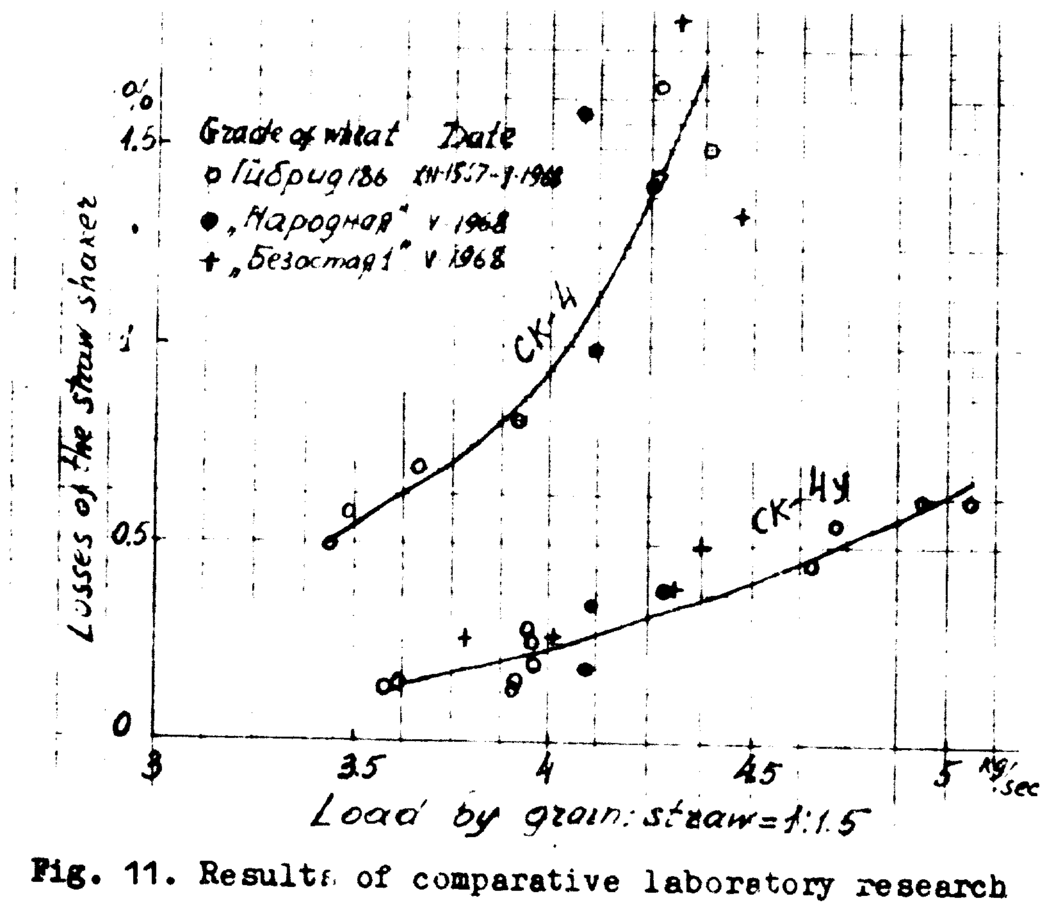


Fig. 11. Results of comparative laboratory research work on threshing-and-separating mechanisms of combine harvesters SK-4 (CK-4) and SK-4U (CK-4У).

The upper curve indicates losses of grain in the straw in the threshing-and-separating mechanism of the serial combine harvester SK-4 with a separating spiked beater which throws the heap upward to the cover and deflector. The lower curve refers to the mechanism that has been re-designed. The alterations introduced were as follows: the angle of contact of the concave (at the outlet) was increased by 38° (from 105° up to 143°); the spiked beater was replaced with a four-blade beater and, finally, the first step of the strawwalker was slightly modified. The overall dimensions and weight of the threshing mechanism remained the same, and losses of grain in the straw being removed were reduced approximately by a factor of 4.

This mechanism is employed in the combine harvester "Armada", Clayson, Belgium. During the comparative tests carried out in the Kuban region in 1966 this combine showed a high capacity owing to the use of the re-designed threshing mechanism and also due to its larger width (1285 mm) (Fig. 12).

During the field tests in 1968 (Fig. 13) in the same region (Kuban) and with the same wheat variety "Bezostaya I" ("Awnless I"), but more yielding (about 50 centners per hectare), with good laden kernels (the weight of 1000 kernels was 47 g), the combine "Armada" showed a higher capacity (6 kg/sec). But this time it was surpassed by the combine SK-4 (6.6 kg/sec) with a threshing mechanism the width of which was 85 mm less and even by the combine S-950 B.M. VOLVO (Sweden) with a much lesser width (185 mm less). This may be accounted for by the fact that in the combine "Armada" there is no receiving beater, the angle of contact in the first section of the concave is small and the separation of the grain is shifted to the second section which is mounted mostly vertically.

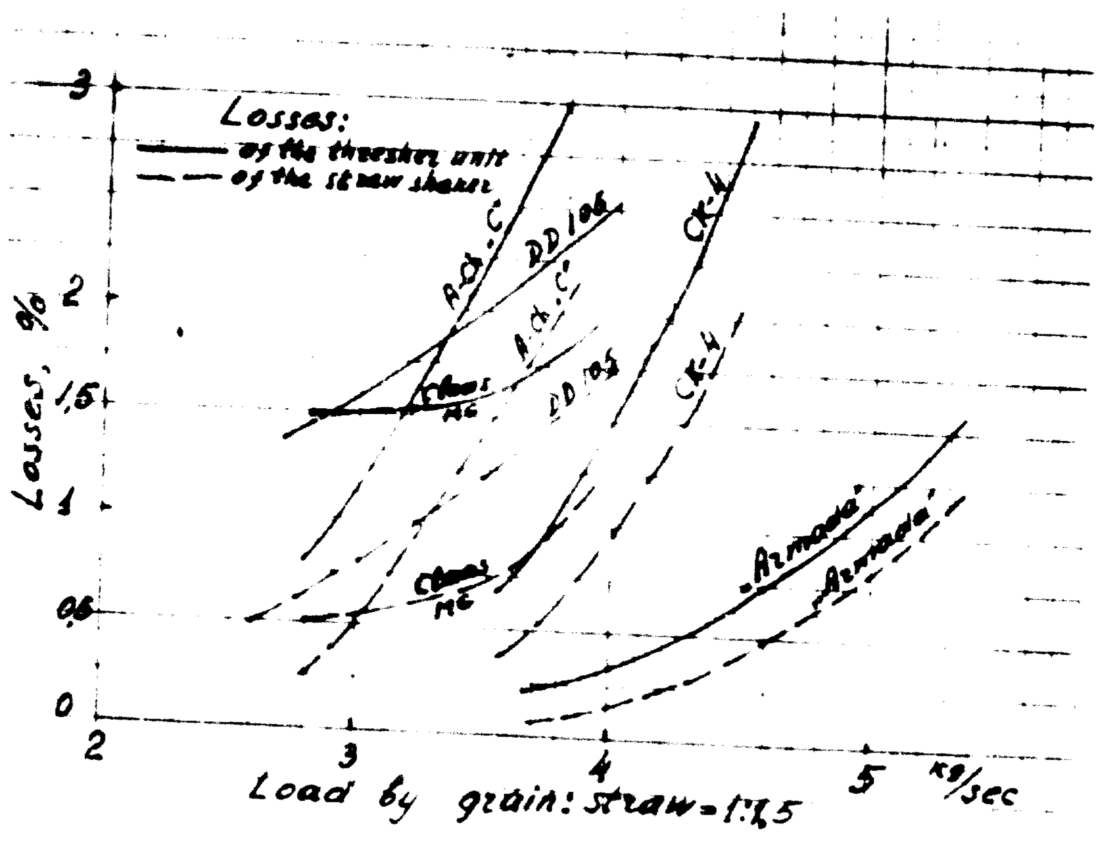


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Fig. 12. Results of comparative tests of combines in 1966, KubNIITIM. Direct combining; wheat "Bezostaya 1".

In this case the wheat was easily threshed under the beater and the greater proportion of the grain was separated at the outlet of the threshing mechanism and through the concave grate pushed forward (in combines SK-4 and S-950).

With a more difficultly threshable wheat (1966) the threshing operation is performed on the front part of the concave, while on the rear part, which has a larger size in the combine Armada, there occurs separation.

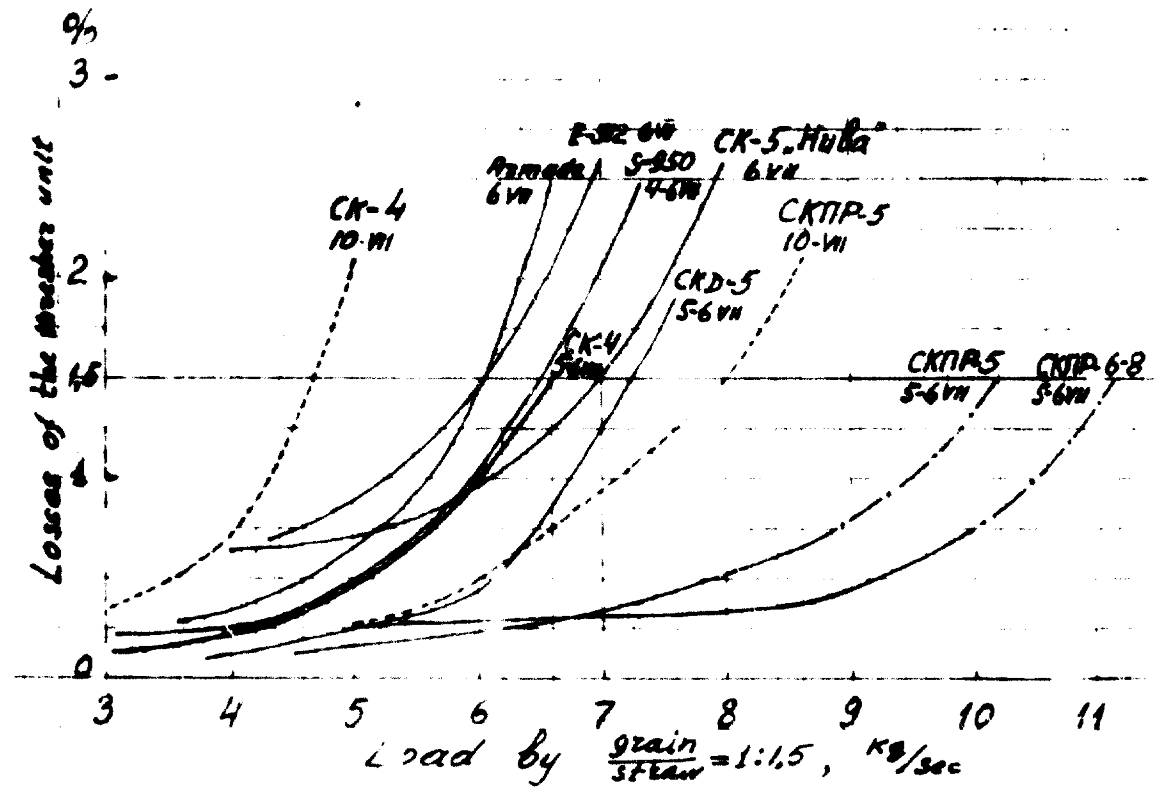

Fig. 13. Results of comparative tests of combine harvesters in 1968, KubNIITIM. Direct combining; wheat "Bezostaya 1"; the moisture content of

	July 4-6	July 10
straw	35-48%	14-20%
kernel	12-13%	10-11%

By the harvesting season in 1967 a set of experimental combine harvesters SKF-4 (СКФ-4) had been put out. These combines, like the combine "Armada", has no receiving beater. They were equipped with a 4-blade separating beater and the angle of contact of their cylinders at the outlet [illegible] was thrown onto the beginning part of the strawwalker. The angle of contact at the outlet of the threshing mechanism was increased by 40°, but at the inlet, because of the elimination of the receiving beater, this angle was reduced by 30° and so in comparison with the combine SK-4 (СК-4) the angle of contact was increased only by 10°. This alteration improved the separating process at the end of the threshing mechanism and on the strawwalker, but the separation at the inlet of the unit was impaired. In the field tests conducted in 1967 the combine SKF-4 did not show any perceptible advantages over the serial combine SK-4. In the course of these tests the receiving beater was restored in the SKF-4 combine, as a result of which the angle of contact was increased up to 143° and the efficiency of its operation was improved. The diameter of the cylinder was also increased from [illegible] to 600 mm, but this slight increase was of no consequence.

In 1968 the combines SK-4 (СК-4) and SK-4M (СК-4М) were tested. The diameter of the cylinder ([illegible] mm) remained unaltered in these combines, but the angle of contact was increased up to [illegible] and use was made of a [illegible]-blade beater which [illegible] onto the inlet of the strawwalker. The operation of [illegible] proved [illegible] was not inferior to that of the combine SK-5 "Niva" fitted with a 600-mm cylinder. These changes have been introduced into the design of the SK-4 (CK-4) combine which are now produced as the SK-4A (CK-4A) model by the "Rostselmash" factory.

Two or three years ago the Sweden firm BM VOLVO put out the S-1000 combine (Figs. 4 and 10) furnished with a receiving beater, where the heap was thrown by the multi-blade separating beater onto the inclined shield. The external appearance of the S-1000 (Fig. 4) was out of date. This combine has been re-designed by the BM VOLVO into the S-95 combine having a modernized external appearance (Fig. [illegible]). Besides, the following slight but essential alterations, providing better operation, have been introduced into the combine: the angle of contact is increased up to 1[illegible]°; the multi-blade beater is replaced with a 4-blade beater throwing the heap onto the inlet of the strawwalker (Fig. 14). During the comparative tests conducted in the Kuban region in 1966 the S-95 combine, the threshing unit of which was 1100 mm wide, showed a higher capacity (6.5 kg/sec) than the "Armada" combine with the threshing mechanism 12[illegible]5 mm wide. The higher capacity was attained due to the presence of a receiving beater and a larger angle of contact.

An interesting combine harvester (E-512) has been developed in GDR, which has a modern external appearance (Fig. [illegible]), and a wide threshing unit (1[illegible]0 mm). The basic

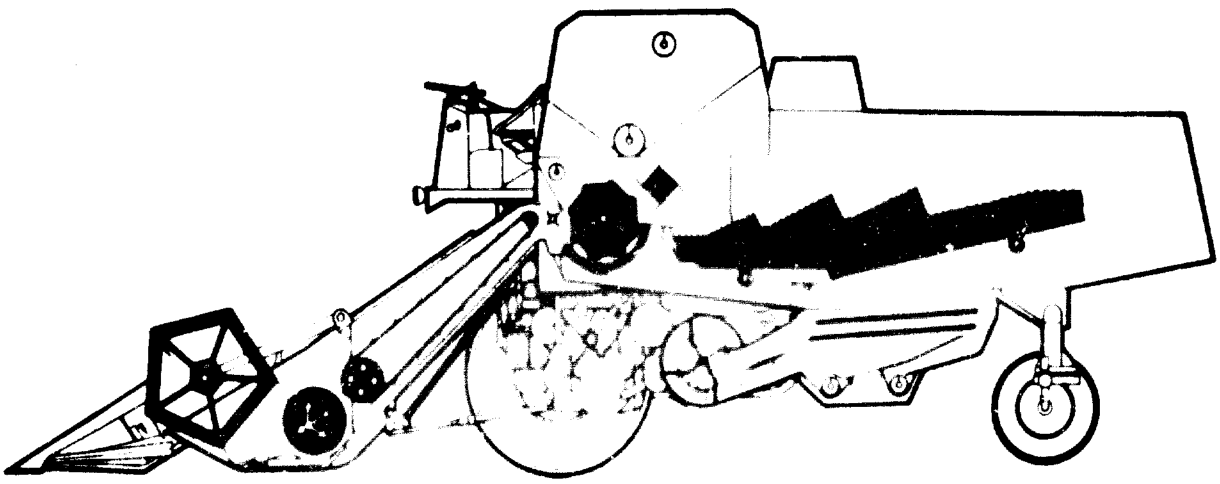

Fig. 14. Schematic of the combine harvester S-950 BM VOLVO, Sweden.

working units of this combine were designed at a high technical level. But the design of its threshing mechanism cannot be considered efficient (Fig. 16). Like in the "Armada" combine harvester, the receiving beater is omitted in this model. Besides, for the reasons that are difficult to explain, the 4-blade beater that throws the heap onto the inlet of strawwalker has been replaced with a multi-blade beater which throws the heap onto the inclined shield, the scheme that was made use of earlier in the S-1000 combine harvester. Although this scheme had been abandoned in Sweden, it was applied later in the GDR.

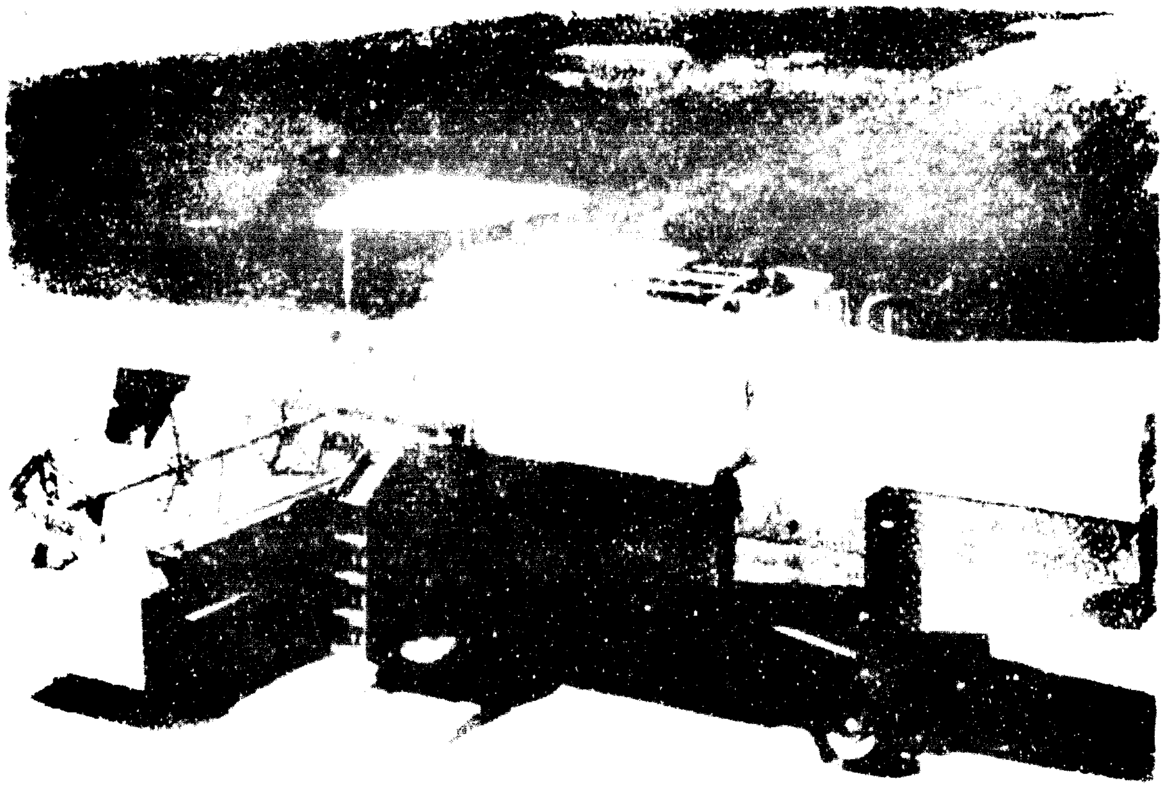

Fig. 15. Combine harvester E-512, GDR

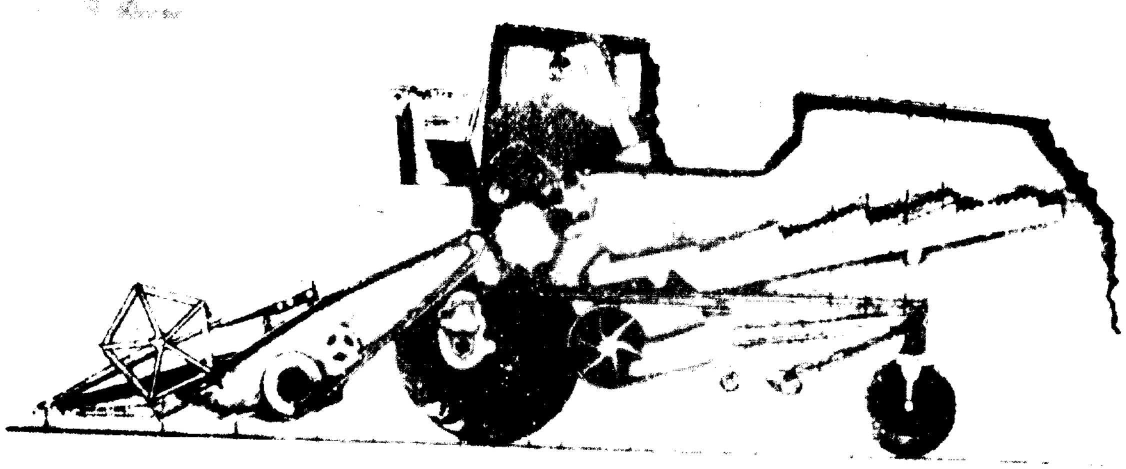

Fig. 16. Schematic of the combine harvester E-512, GDR

As a result, the angle of contact of the cylinder in the E-512 combine is unreasonably small, and this reduces the throughput of its threshing unit. It is believed that this error will soon be corrected, since it is not difficult to increase the angle of contact at the outlet, replace the beater with a 4-blade one and change the direction of the heap. The absence of the receiving beater still makes it impossible to increase the angle of contact of the cylinder, to 138-143° (cf. S-950, CK-4A and CK-5 "Niva"), but this drawback will be compensated for by the use of a wider threshing unit (1300 mm).

Table 2 gives the relative capacities of some combines on the basis of the results of the tests carried out in 1966 in the Kuban region (Fig. 12) at a tolerable level of grain losses in the threshing unit (1.5 percent) and in the strawwalker (0.5 percent).

Table 2

Model of combine, firm, country	Feed (kg/sec) at losses	
	1.5 percent, threshing unit	0.5 percent, strawwalker
105, John Deere, USA	2.9	2.6
"Matador Gigant", Claas, GFR	3.0	2.8
Gleaner "C", Allis Chalmers, USA	3.2	3.0
CK-4, USSR	4.0	3.7
"Armada", Clayson, Belgium	5.3	4.6

The results of the tests accomplished in 1968 (Fig. 13) are presented in Table 3.

By comparing the results given in Tables 2 and 3, we can see that the combines CK-4 and "Armada", which were tested in both cases, showed better results in 1968. This can be accounted for as follows. First, as indicated above, in 1968 the grain of "Bezostaya 1" wheat being harvested was large and full-weight (the weight of 1000 grains was 47 g) and easier to thresh and separate. Second, in 1968 the tests were carried out at the very beginning of full ripening of wheat, when its stalks had not yet lost their intercellular moisture. The grain was already dry enough (moisture content 12-15 percent), and the straw wet (31-48 percent) due to the intercellular rather than surface moisture. The surface of this straw was dry enough and consequently the passage of the grain through the straw heap was much easier. When the ripened and sufficiently dry stalks are wetted from over the ground (rain, dew), the net moisture content can be increased, though slightly, but this will be enough for the coefficent of resistance to increase noticeably, and hence threshing and separation will be more difficult to accomplish.

During the tests in Siberia in 1966 it was noted that the threshing losses in the same combines in a test lasting 18-19 hours with the weather getting cold and the relative humidity of the air increased, rose 2 or 2.5 times as compared with the results obtained 2 or 3 hours earlier (in a test lasting 15-16 hours).

Table 3

Model, firm, country	Date	Moisture content, %		Feeding (kg/sec) at losses	
		straw	grain	1.5%, threshing	0.5%, strawwalker
"Armada", Clayson, Belgium	July 6	40	13	6.1	5.9
E-512, GDR	July 5-6	40-48	13-14	6.1	4.8
S-950, BM VOLVO, Sweden	July 4-6	32-48	12-15	6.5	5.7
CK-4, USSR	July 5-6	48	13	6.6	6.0
CK-5, USSR	July 6	36-41	12-13	7.0	-
CKD-5, USSR	July 5-6	41	13	7.2	6.6
CKΠP-5, USSR	July 5-6	36-41	12	10.0	8.5
CKΠP-6-8, USSR	July 5-6	41	13	11.0	9.8
CK-4, USSR	July 10	13.7	10.5	4.7	4.7
CKΠP-5, USSR	July 10	20.0	11.0	8.0	6.7

The moisture content of the straw and grain as determined by conventional methods (in drying chambers) practically remained constant. The moisture precipitated onto the surface of the stalks as a thin film and this was enough to impair the indices.

Unfortunately, efficient methods for determining the surface moisture are not available at present. They could show that in tests of July 4-6 (Table 3), inspite of the very high net moisture content of the straw (31-48 percent), its surface moisture content was small. Four or five days later (July 10) two combines CK-4 and CKΠP-5 were subjected to control tests, the results of which are shown in Fig. 13 (dashed line) and in Table 3 (the two lines from bottom). Only 4 days elapsed since the time of the basic tests, but these were very hot days and the moisture content of the straw was reduced, the heap (grain-and-returns) became finer and the threshing losses at the same feed increased 3 times and the capacity diminished by 20-30%.

The test conditions (July 4-6) were highly favourable in all respects (large laden grain, insignificant chopping of straw, uniform feed, etc.), losses were lowest, the capacity highest among the results obtained at different times in other regions.

In the same year (1968) during the test conducted in the Ukraine with the winter wheat "Mironovskaya 808" (yield 32 centners per hectare; large, but sickly grain) all the combines under test showed much lower results (Fig. 17) which are typical for the conditions most frequently encountered.

The capacity at 1.5 per cent threshing losses was: 3.5 kg/sec for CK-4; 4.6 kg/sec for E-512; 5 kg/sec for CK-5 "Niva"; 5.1 kg/sec for CKD-5; 5.5 kg/sec for CKП P-5; and 6.4 kg/sec for CKП P-6-8.

Figure 18 shows the results of testing of the same combines (except for the last) in the harvesting of winter rye.

The capacity, also at 1.5 percent threshing losses,

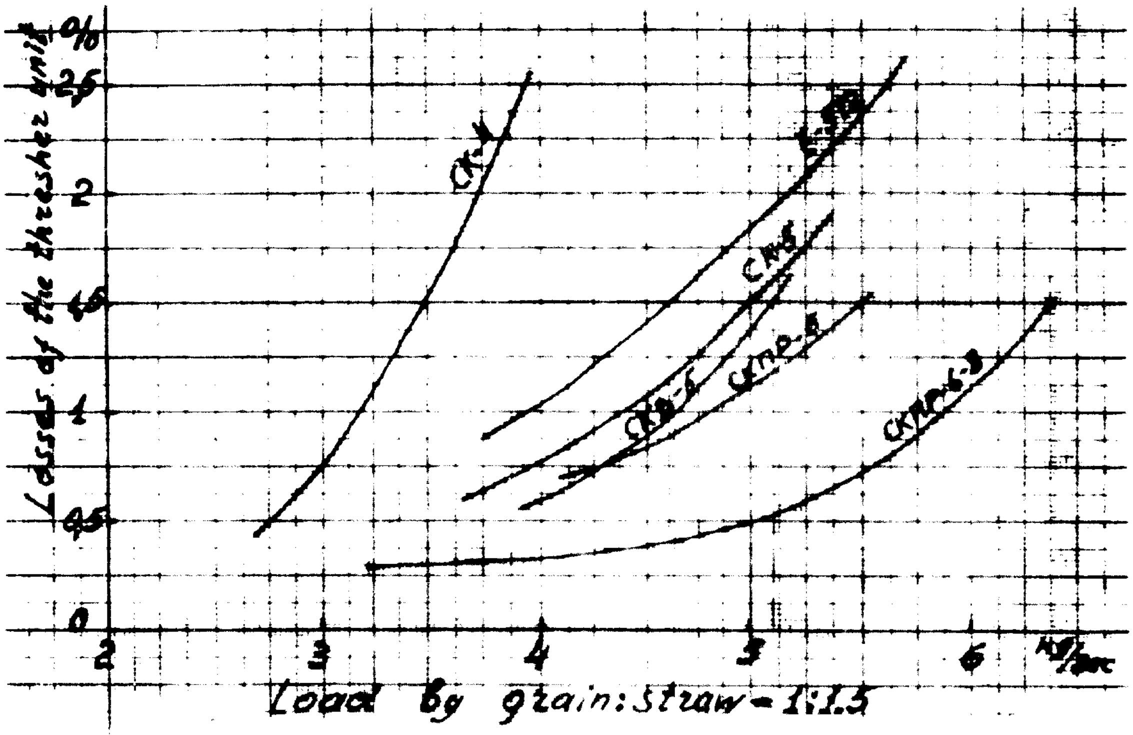

Fig. 17. Resu. 's of comparative testing of combine harvesters in 1968 (the Ukrainean Machinery Testing Station; winter wheat "Mironovskaya 808", yield 32 centners per hectare).

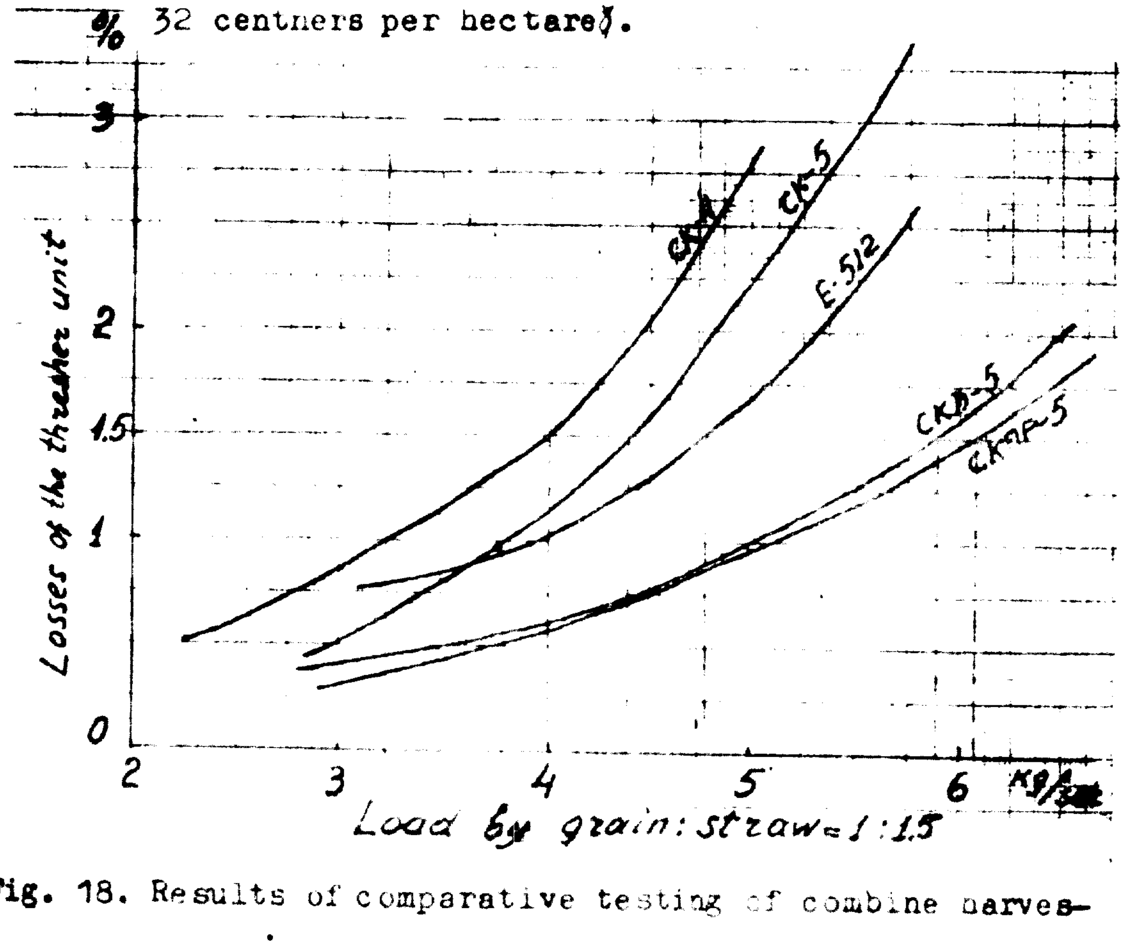

Fig. 18. Results of comparative testing of combine harvesters, 1968; the Central Machinery Testing Station (the Moscow region); winter rye "Gibridnaya 2".

was: 4.0 kg/sec for CK-4; 4.4 kg/sec for CK-5; 4.8 kg/sec for E-512; 5.9 kg/sec for CKD-5; and 6.1 kg/sec for CKПP-5. Here the E-512 combine showed relatively better results mainly due to more uniform feed of the stalks from the reaping section to the threshing unit. It was noted that, inspite of its great operating width (5.7 m), the E-512 combine harvested long-stem rye well, whereas in the headers of the other combines with their shape reproducing ground contour the stalks were delayed on their way from the auger to the inclined elevator and the feed was uneven. However, when short-stem and laid grain crops were harvested by the E-512 combine, losses increased because of the absence of the longitudinal and lateral fitting of the header shape to ground contour.

Figure 19 shows the results of testing of combines at the Tselinograd Mashinery Testing Station in Kazakhstan for harvesting short-stem awned spring wheat "Bezenchugskaya 98". In those tests the capacity of all the combines was high (at the same level of threshing losses, 1.5 percent): 4.9 kg/sec for CK-4; 6.0 kg/sec for E-512; 6.3 kg/sec for CK-4M (modernized CK-4 model with increased angle of contact, 143°, and expanded cleaning unit); 6.6 kg/sec for CK-5; 6.7 kg/sec for CKD-5; and 7.9 kg/sec for CKПP-5.

Analysis of the test results given in Figs. 13, 17, 18 and 19 shows that in all the cases when harvesting winter and spring wheat varieties and rye in the regions of the USSR differing in the climate the highest capacity was

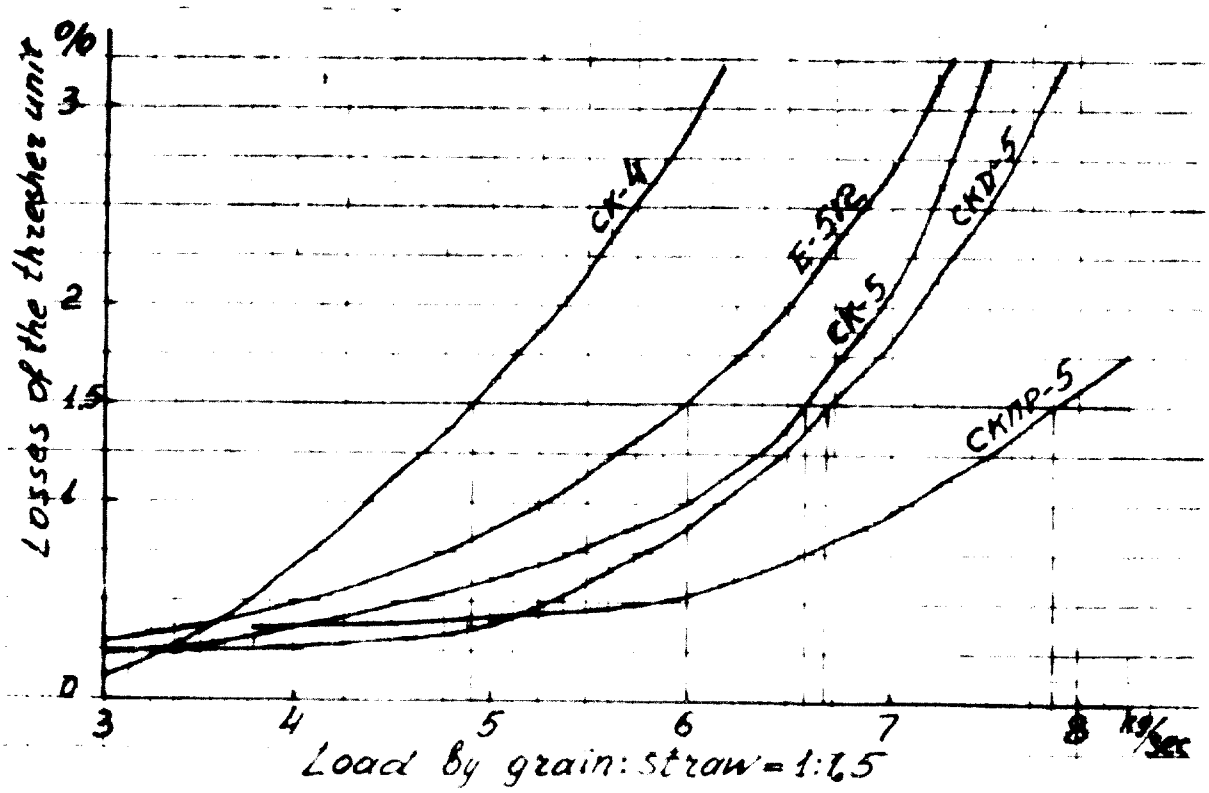

Fig. 19. Results of comparative testing of combines at the Tselinograd Machinery Testing Station, 1968, picking windrows of spring wheat "Bezenchugskaya 98".

demonstrated by the two-cylinder combines CKD -5, CKПP-5 and CKПP-6-8, especially the last two combines, which were equipped with an intermediate reversing beater. The same combines, with the first rasp-bar cylinder being replaced with a spiked cylinder, also showed good results in the harvesting of rice.

With equal dimensions (length and width) of the separating surface these combines showed a higher capacity (by 50-70%) as compared with the formerly produced CK-4 combine.

The introduction of slight changes into the design of single-cylinder combines, namely, increase of the concave angle and the throw of the heap (grain-and-returns) by the four-blade beater to the inlet of the strawwalker, permits increase of capacity by 30-40 percent.

5. Separation Reguliarities and Determination of the Capacity of Combine Harvesters

Modern combine harvesters built by numerous firms in various countries have many features in common: auger header, floating inclined conveyor, cylinder, strawwalker and one two-screen cleaner. A great variety of combinations of the width and length of threshing-and-separating units, and different concave angles and other differences, are, however, encountered, which affect the operation of combines and make it difficult to comparatively assess their capacities.

The capacity of grain combines is most frequently limited by the losses in the strawwalker, because it is these losses that increase more rapidly than the feed (this increase is a power function of the feed).

In isolated cases, when the straw is very dry and the cleaning unit is overloaded, it is the cleaner, rather than the strawwalker, that limits the feed. With difficultly threshable crop varieties the feed can be restricted by the losses from unthreshed grain, though this occurs seldom, because in setting the required clearances in the threshing mechanism and the cylinder speed the amount of returns, as the feed is speeded, increases insignificantly.

In the USSR, the 0.5 percent losses each in the straw-walker, in the cleaning unit and from unthreshed grain,and the total 1.5 percent threshing losses are considered tolerable. The capacity of grain combines are specified on the basis of these losses.

Much work has been done in the USSR for investigating the reguliarities of separation of coarse grain-and-returns with a view to determining the output of threshing-and-separating units. As a result, a number of mathematical relationships have been proposed.

It is well known that the capacity is linearly dependent on the width of the threshing mechanism, the relation between its length and capacity is represented by a very complex law.

Investigations carried out at the All-Union Research institute of Agricultural Machine Building allowed us to arrive at the following relationship between relative losses ζ (feed of grain to separator inlet is assumed to be unity) and separator length L_s (distance from the point the stalks enter the threshing unit and the end of strawwalker) and feed of straw per unit width of the separator

q_s $\left(\frac{kg}{sec \cdot m}\right)$:

$$\zeta = \frac{k}{L\, e^{\frac{m}{nq_s}}}$$

where k, m, n = experimental coefficients

e = base of natural logarithms

From the above equation it follows that

$$q_s = \frac{1}{n \log e} \log \frac{m \log L}{\log \frac{k}{\zeta}}$$

With given losses ζ, straw factor λ (ratio of straw weight to total weight of grain), length L and width b of separator the permissible feed (capacity) is equal to:

$$Q = \frac{q_s B}{\lambda} = \frac{B}{\lambda n \log e} \log \frac{m \log L}{\log \frac{k}{\zeta}} .$$

Assuming that $\frac{1}{\lambda n \log e} = \eta$ and $\frac{m}{\log \frac{k}{\zeta}} = \theta$,

we get:

$$Q = \eta B \log (\theta \log L).$$

For the majority of present-day combine harvesters (CK-4, Massey Ferguson 50^{U}, John Deere, etc.), in which the concave angle ranges from 100 to 120^{o} and the heap is thrown to the cover or inclined shield, these coefficients may be assumed to be equal to:

$$\eta = 4.8; \quad \theta = 6.8.$$

For the CK-4 combine (B = 1.2 m; L = 4.41 m) the capacity Q = 4.8 B (6.8 log L) = 3.7 kg/sec, which is actually the case under average conditions (Fig. 12).

For the Massey Ferguson 500 combine (B = 1.14 m, L = 3.33 m) the capacity *Q* is equal to 3.0 kg/sec. When this combine was tested in the Kuban region in 1965 together with the CK-4 combine, it had the same losses of grain in the strawwalker at a feed of 3 kg/sec as the CK-4 machine at a feed of 3.7 kg/sec.

For the "Matador Gigant" combine, Claas, GFR (B = 1.25 m, L = 3.83 m) Q = 3.6 kg/sec. In comparative tests conducted in the Kuban region in 1966 the losses in the strawwalker in this combine was 0.5 percent (ξ = 0.005) at a feed of 2.8 kg/sec (Fig.12).

As was pointed out above, the throw of the heap by the rear beater onto the inlet of the strawwalker aids in improving the separation and increasing the output of the separator. For this throw to be accomplished there must be provided an ample space between the rear beater and the surface of the first step of the strawwalker. If the distance between them is small (space is confined) the heap is retarded in its movement and accumulated as a thick layer. When a fresh portion is fed, it meets the previous one and is thrown back to the cover of the threshing unit, as a result of which the separation efficiency is reduced.

Favourable conditions for the throw of the heap onto the strawwalker inlet have been developed in a number of combines: "Armada", Clayson (Belgium); "Titan", Bautz; Fahr, M 66 (GFR); "S-950", BM VOLVO (Sweden), etc., and also in combines built in the USSR: CK -5 (Krasnoyarsk factory); CK-4A (Rostov factory) and in experimental models "Niva" and "Kolos".

Besides, in new combines built in the USSR and in the S-950, BM VOLVO (Sweden) combine the angle of contact or envelop of the cylinder by concave (concave angle) is increased to 138° (S-950), 143° (CK-4A) and 146° ("Niva" and "Kolos"). As may be seen from the test results indicated above, the use of these two refinements makes it possible to obtain the highest output of the separator. For these combines the coefficients in calculations of the output may be assumed to equal:

$$\eta = 6.8; \qquad \theta = 6.3$$

For the S-950 combine (B = 1.1 m; L = 4.08 m) Q = 4.4 kg/sec.

For the CK-4A, CK-4M and CK-5 combines (B = 1.2 m; L = 4.41 m) Q = 5.0 kg/sec.

In the "Armada", "Titan", M 66 and other combines there is no receiving beater and the concave angle is 30-40° less, which reduces the capacity as compared with the theoretical.

The highest capacity is provided by combines with two-cylinder threshing-and-separating units, the coefficients for which may be assumed to be equal to:

$$\eta = 7.6; \qquad \theta = 6.2$$

For the CKД-5 and CKП P-5 "Niva" (B = 1.2 m; L = 4.41 m) Q = 5.5 kg/sec.

For the CK P-6-8 combine (B = 1.5 m; L = 4.37 m) Q = 6.9 kg/sec.

In tests the capacity of combines is established on the basis of the feed corresponding to 1.5 percent threshing losses (0.5-0.7 percent of these losses comes from unthreshed grain in the cleaner), the share of the strawwalker being 0.8-1 percent. In this method of calculation the resulting capacity is 10-15 percent higher than according to the above-given formula. It seems more correct that the calculations should be based on the losses in the straw walker (0.5 percent), and only in relatively rare cases, when the straw is heavily chopped and the cleaning unit is overloaded and loses more grain than the strawwalker, the capacity should be determined on the basis of threshing losses (1.5 percent).

The theoretical capacity refers to the operation of combines under average conditions. The actual or service capacity of combines varies over very wide ranges, depending upon the properties and condition of the crops being picked. Under unfavourable conditions (awned varieties of wheat and barley, sickly grain) the capacity of a combine of the CK-4 type is 2.5-3 kg of bulk grain per second or 3.6-4.3 tons of grain per hours, while under favourable conditions (awnless wheat with large laden kernels) it rises up to 6-7 kg of bulk grain per second or up to 8.5-10 tons of grain per hour.

In case of grain crops with a small amount of straw the output of grain reaches 12 or 13 tons per one hour of the net operating time.

The properties of the crops picked at the harvest time and even during one day vary so widely that it is very difficult to compare the results of tests conducted in different regions and at different times. The properties of, say, metals vary over a considerably narrower range than those of the crops. However, modern mechanical engineering is impossible without the use of numerous means for determining the properties of the materials being worked (hardness, strength, viscosity, etc.). The need for the use of appropriate means for determining the objective indices characterizing the properties of the crops being threshed has long been felt. Two devices have been developed for this purpose at VISKhOM (All-Union Research Institute of Agricultural Machine Building) for measuring the threshability of grain crops (Fig. 20) and grain crushability (Fig. 21). These devices were called "classifiers". In the threshability measuring device the stalk is secured to the end of the lever. When the lever is thrown from one of the 10 steps (classes), the stalk is set in motion by the spring; its velocity ranges from 2 to 20 m/sec. Striking against the bumper the lever with the stalk is stopped, and the grains, acted upon by the forces of inertia, use the kinetic energy acquired and are separated from within the stalk at the corresponding steps.

The difficulty of threshing (threshability) is characterized by the distribution of the threshed grain among the classes (steps). This device also permits determination of the energy required for the removal of the grain from the stalk with its mass and velocity at which it was separated being known.

In the crushability "classifier" the grain is placed in a clamp and struck by the edge of a plate which is attached to the end of the lever actuated by the spring. Before striking the plate has one of the 10 speeds from 5 to 50 m/sec, depending upon which step the lever was moved to prior to the impact. These devices can be used by plant breeders for the assessment of the properties of new varieties of grain crops being develped. The threshability "classifier" has been highly estimated by the strain testing commission as a device permitting assessing not only threshability but also the shattering ability of the grain in the standing crop.

Unfortunately, no devices are available at the present time for estimating other properties of grain crops such as, for example, separability, surface moisture content. The development of such devices must be given more attention.

The use of the most acceptable unified procedure for conducting laboratory and field tests of combines is of great importance for obtaining most reliable data and providing the possibility of their comparative estimation.

It would be strongly desirable to develop such unified procedure on the basis of generalization of the experience

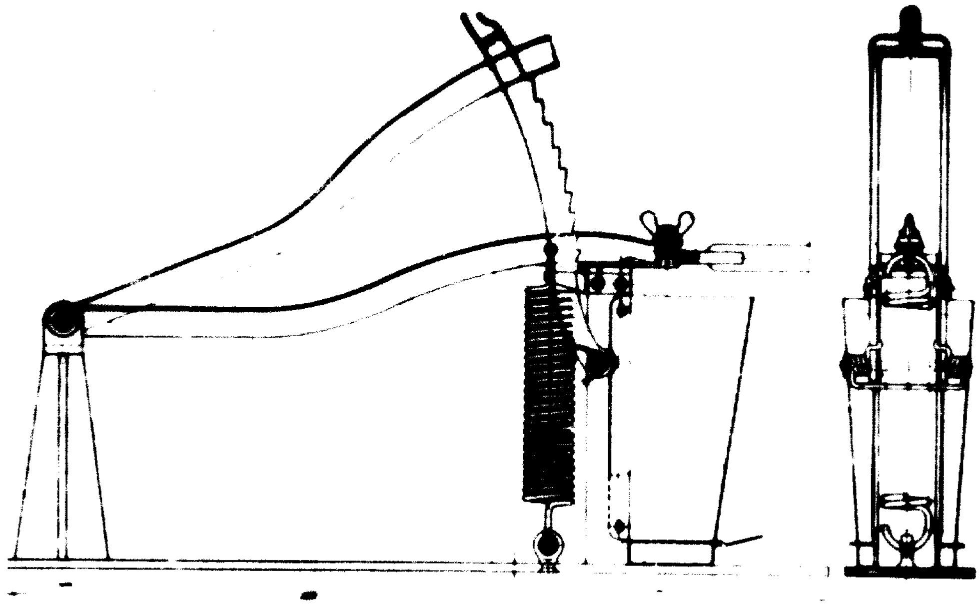

Fig. 20. Device for measuring threshability of grain crops (threshability "classifier").

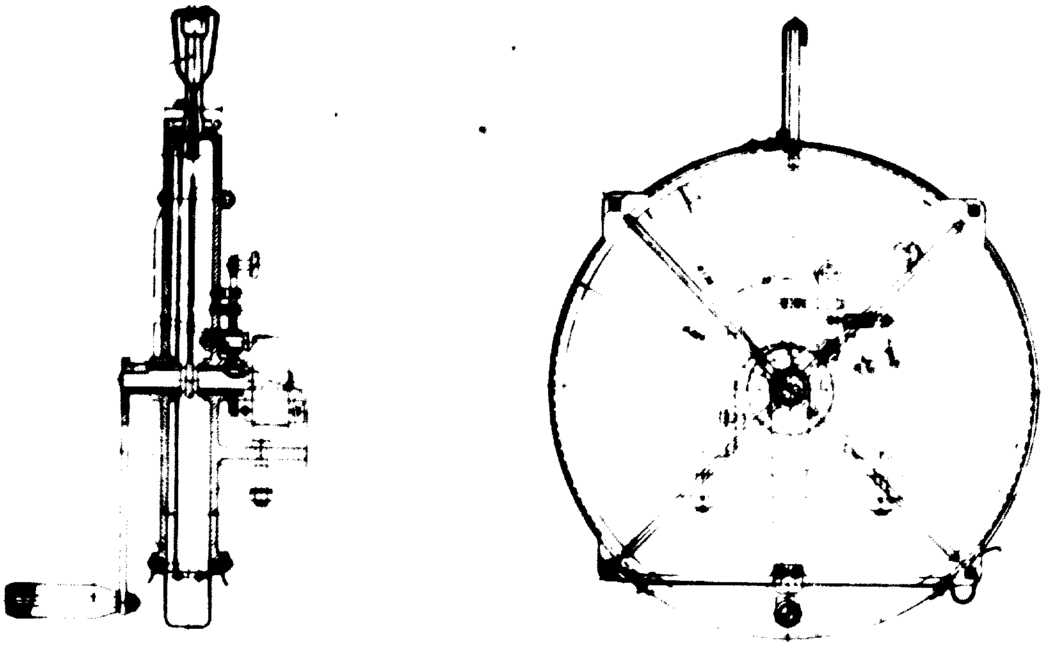

Fig. 21. Device for measuring grain crushability (crushability "classifier").

gained and to use it for testing of combines under a variety of conditions characteristic for the developing countries.

6. Harvesting Grain Crops by Using Industrialized Methods

The process of grain harvesting even in the most developed countries is accomplished under big strain and requires considerable labour expenditure and a great number of various technical facilities. All these circumstances are an obstacle to reducing the cost of product, and leads to the prolongation of the harvesting time and increase of grain losses.

The processes of cutting, threshing and separation accomplished by the combine harvester require relatively less labour expenditure--less than one man-hour per hectare or 0.5 man-hour per ton of grain, whereas the labour required for double transportation of the grain, first from the combine to the grain-handling plant and then to the grai storage or to the elevator, is 3 or 4 times greater.

The combine hopper with a capacity of 1.2-1.5 ton of grain, is filled up in 10 or 12 minutes. The 3-ton truck takes the grain from two combines and in order to provide continuous operation of the latter three such trucks are required if the radius of grain transport is from 3 to 5 km. Attempts to deliver the grain from combines to the elevator at a transport radius of 15-30 km have been unsuccessful, since too many trucks were needed, and the synchronism of their approach to combines was violated, as a result of which much operating time was lost.

In recent years hoppers of increased capacity (25 tons of grain) have been installed on combine harvesters. However, without increasing the load-carrying capacity of grain trucks this measure is useless, because a 3-ton truck will take the grain not from two combines, but only from one and the number of trucks required will not be reduced.

To reduce the required number of trucks wide use is now made in the USSR of truck-trains (a truck with one or two trailers), but they are used for delivering the grain from the processing plant to the elevator, since their use for unloading the grain from the combine is hampered by their low manoeuvreability and unwieldiness.

Of interest in this respect is the work carried on currently in GDR for realization of the industrialized method of grain production. This method consists in using a line of 5 combines E-512, discharging the grain from all these combines into one truck (12-15 tons) and transporting it directly to the industrial centre for cleaning, drying and processing the grain, which is capable of receiving and processing up to 100,000 tons for a season. This industrial centre includes a combined-fodder plant which services the animal farmings of a particular area.

The necessity of a sharp increase of the load-carrying capacity of trucks employed for transporting the grain from the combines is highly evident, the more so that in the harvesting of other agricultural crops (silage, potatoes, cane, and others) the effectiveness of use of these machines is beyond any doubt.

For the last 20 years the load-carrying capacity of trucks employed in industry and in construction has increased manyfold and is now 15-25-40 and even 75 tons; in agriculture matters have changed little.

The labour expended in picking straw left by combine harvesters is several-fold higher as compared with grain harvesting; therefore in some countries all the straw or the greater part of its is left in the field. Many countries have to paick the straw and use it.

In all the countries where the straw is removed from the field and used, a tendency appeared to relieve the combine of unwieldy facilities intended for removal of straw, to place it in windrows and then pick up by other machines which are also designed for harvesting hay (balers, chopping pickups, stack-forming pickups).

A great amount of labour is expended in picking up the straw in Gdr using a baler K422, where bales are thrown over into the trailer (Fig. 22). This machine is operated by one driver. Hand placement of bales is excluded.

Much labour force is required for stacking the straw, loading it into the transporting facilities, delivering it to animal farmings and for stacking it again. Therefore in the USSR many attempts have been made to pick up the straw so as to from-stacks resistant to atmospheric precipitation,

Fig. 22. Baler K 442 with throw of bales into trailer, GDR.

to leave them till the end of harvesting operations along the edge of the field and later to deliver without damaging them to the farm and leave there for further storage till they are needed for use.

Of interest is an automatic stacker built in the USSR, which makes a round tight stack of crushed straw 20 m^3 in volume and about 2 tons in weight. In such a stack the straw is stored well (only a small proportion in the top layer is damaged). The straw can be taken from the field without being danaged at a convenient time and delivered to the farm by special stack-mover (Fig. 23).

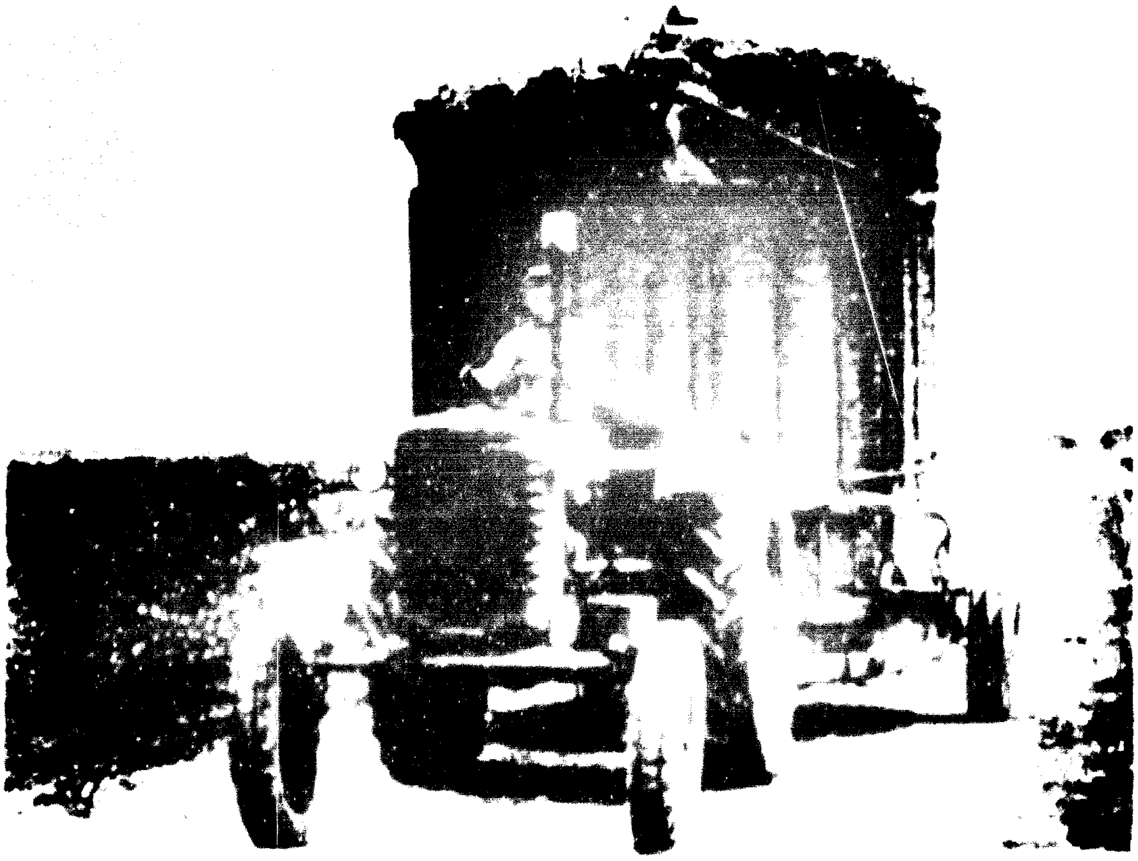

Fig. 23. Transportation of stacks made by automatic stacker АСП-20, USSR.

The usefulness of removal of the straw or any part of it should be decided for each particular case, with concrete conditions being taken into consideration.

7. Recommendations

On the basis of the experience gained in the countries with a highly developed state of industry the developing countries should take up the use of the most improved and productive combine harvesters and windrow harvesters and a rational combination of direct and windrow combining methods.

Transportation from the combines, cleaning, drying (where necessary) and processing of grain is expedient to accomplish through the use of industrial methods, and trucks of high-capacity with direct delivery of grain to the industrial combination plants. Experience shows that new, most advanced, methods are easily introduced in the areas where mechanization has just started and there are no established traditions.

In order to choose the most efficient machines for use in developing countries and to work out detailed well-grounded recommendations it is necessary:

-- to study the concrete conditions typical for the harvesting of grain in these countries, and to obtain the data characterizing the sizes of lands under crops to be harvested, the features of ground contour, variations in the properties and condition of crops and of the soil at the harvest time;

--to conduct tests of combines and other harvesting machines under the conditions typical for developing countries and to elaborate a tentative procedure for carrying out these tests on the basis of generalization of the experience gained.

—to find out the straw requirements in animal farming and elsewhere the expediency of pickup of all the straw or any part of it in whole, crushed or pressed form.

To create the conditions contributing to the efficient application of advanced methods of grain harvesting and of the most improved and productive combines and other machines, it is necessary to determine the most acceptable forms of machine utilization to suit the particular conditions in developing countries (organization of big state economies, organization of hiring of machines, production cooperations and other forms of cooperative use of agricultural machinery by small-scale economies).

7. 7. 72