DEVELOPMENT OF OSCILLATING CLASSIFIERS FOR FORAGE CHOP LENGTH DETERMINATION

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ABSTRACT
The chop length produced by forage harvesting systems is an important factor in many aspects of silage production. The only reliable method being tedious hand measurement of every particle in a sample of chopped material. Three oscillating particle length classifiers have been developed. Each of them differed from one another in their stroke patterns. The three different drive-mechanisms produce three screen motions: Linear motion, Under-arc motion and Gyratory motion. Effects of the stroke patterns on forage particle size separation is studied by using identical screen boxes. A procedure for calculating forage particle size is defined. The size of the particles are reported in terms of geometric mean length and geometric standard deviation by weight.
The particle size determined is used to evaluate forage harvesting machine and to define forage characteristics with regards to animal feeding trials.

1. INTRODUCTION

The mechanization of forage crops harvesting depends on the ability of a forage harvester to convert long stemmed crops into suitable short length pieces for silage purposes. Usually forage harvesters do not produce the same length of cut pieces as they are designed to do. Within a representative sample of chopped material from a machine it is not usual to find particles ranging from less than 1mm in length to 100mm with the mean length substantially greater than the machine setting [1].
There is no definite method or system for defining particle size of chopped forage. The lack of such a system has affected the ability of researchers to make valid comparisons of separate animal feeding trials where chopped forages are involved.
The absence of such a system also limits the extent to which comparisons on the chopping effectiveness of harvesting machines are made. Most often only the forage harvesting machine forms the basis for defining forage particle length. Even then this is inadequate because of the wide range of particle size produced by a machine.
The labour intensive process of hand sorting to determine particle length has obvious limitations when it is realized that a kilogram sample of chopped forage may contain as many as half a million particles.
Conserved forage in the form of silage forms a major part of the diet for livestock. The chop length of forage is an important factor which determines the efficiency with which forage is conserved and utilized. Successful conservation in the form of silage demands the exclusion of air, which can be expelled from an ensiled forage by compaction. The exclusion of air improves fermentation which subsequently increases the quality of conserved nutrients. A reduction in chop length of forage helps compaction but increases the power required for chopping forage. Barrington et a1 [2] and Jorgensen et a1 [3] reported on the variation in the performance of livestock with variations in chop length. Improvements in performance result from an increase in the voluntary

intake of short chopped' forage, which in turn is determined by the rate of appearance of digest from the reticularemen. The rate of disappearance is a function of the rate of breakdown and is affected by the physical characteristics of the forage.
Forage handling as associated with tower silos and vacuum silos require short length of chopped forage for satisfactory operation. Unloading form clamp silo becomes increasingly difficult as chop length increases. Thus, an ideal chop length for a specific conservation system cannot be made until further evidence is available. The collection of this evidence will rely on accurate systems for classifying forage particle length and a good procedure for expressing forage particular size.
Thus the specific objectives of this study were:

1. To develop and construct oscillating screen classifier which will accurately separate chopped forage into fractions by particle length.
2. To evaluate the effect of the stroke patterns of the oscillating classifier on forage particle length separation.
3. To establish a method for calculating and expressing the particle length of chopped forage.
4. Description of the Oscillating particle length Classifiers.

2.1 Linear Motion Classifier

The screen box for this machine is supported on machined high-density polyethylene rails so that the screens move in a straight line in a horizontal plane. The crankshaft and connecting rod assembly provide four different stroke lengths. A chain drive between the gear motor and crankshaft permits variation of the oscillating speed.
Two counterweights, each with a mass equal to one-half the mass of the screen box are used to balance the forces of inertia of the screen box. The counterweights are chain driven from the sides of the box and are carried on the rails alongside the box so that they move in a straight line in a horizontal plane, and at the same level as the centre of mass of the screen box. The direction of movement of the counterweight is always opposite to the direction of travel of the screen box.

2.2 Under-arc motion classifier

An under-arc motion is provided by supporting the screen box on vertical links on the sides of the screen box. The links have a fixed bearing centre distance of 102 mm. As the box is driven by the crank and connecting rod, it travels generally horizontally, but upward on each end of the stroke.
Four counterbalancing weights are attached to the vertical extensions of the supporting links. The weights have masses equal to one-fourth the mass of the screens and the screen box. Their centers of mass are located in the same horizontal plane as that of the screen box at the stroke center. The crank wheel is provided with four different crank pin locations to vary the stroke length. A chain drive between a gear motor and the crankshaft permits changing the speed of oscillation.

2.3 GYRATORY MOTION CLASSIFIER

This classifier is driven by a vertical crankshaft. Two rigid arms support the driven end of the screen box and are connected to the crank arms. The driven end of the screen box is driven in a horizontal elliptical path. The opposite end of the screen box is supported on rails and is driven in a horizontal straight line.
Counterbalancing is provided by a semi-circular counter-weight on the crankshaft with its center of mass diametrically across from the

crank pins. The center weight mass is equal to about one-half the mass of the screens and screen box. Four different operating positions are provided for the counterweight to allow it to be repositioned when the screen box stroke length is changed.

3. OSCILLATING SCREENS

The particle classifiers are each equipped with a stack of five large rectangular punched screens. The holes are square and the screens are 406 mm wide, 565 mm long and the thickness is as indicated in Table 1. The screens are supported by sheet metal frames with depths of 63.5mm and arranged in a stack such that the screen with the larger opening size is at the top. Those with smaller openings are arranged with progressively smaller hole sizes below each other.

Figure 1 shows the general sketch of the oscillating classifiers.

4. EVALUATION TESTS

Series of tests were conducted to evaluate the three different stroke patterns provided by the classifiers. The three machines were set up to operate at the same speed of 144 rev/min and with similar stroke lengths. The same set of punched aluminium screens were used in each machine

Table 1: Specifications for square hole sizes and screen thickness.

Screen No	Norminal size Opening (mm)	Square hole Diagonal (mm)	Screen Thickness(mm)	Open Area %
1	19.0	26.9	11.2	45.0
2	12.7	18.0	9.9	33.0
3	6.35	8.98	4.8	33.0
4	3.17	4.48	3.0	33.0
5	1.17	1.65	0.64	41.5
pan	-	-	-	-
14 mesh woven wire cloth with 0.64 mm diameter wires.				

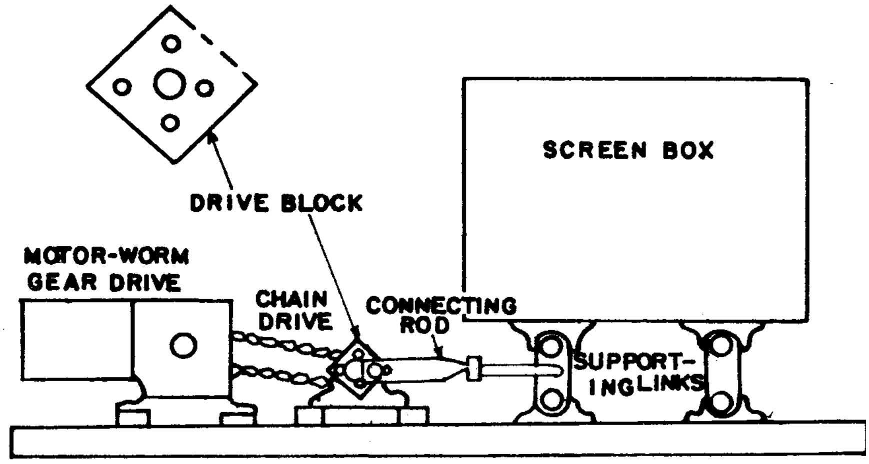

Fig. 1 Schematic diagram of the oscillating particle length classifier.

Samples of freshly chopped alfalfa and corn were used in the investigation. The alfalfa sample was chopped at 6.4 mm theoretical length of cut. The corn sample was also chopped at 6.4 mm theoretical length of cut but with a forage harvester equipped with a 102 mm square hole recutter screen.

The separation runs were made by using the punched screens first, in one machine and then placing them in another in sequence such that the machines are alternated. Six runs were made with the alfalfa sample and four runs with the corn sample. The amount of separated material retained on each screen was weighed and expressed as a percentage of the total weight. Mean percentages and standard deviations were calculated as shown in Table 2 and 3.

The standard deviations for a complete set of runs for each machine and each material were then pooled to provide a measure of repeatability for the set of runs. The lower the pooled standard deviation value, the more repeatable the test was considered to be.

High speed motion pictures were taken of each of the classifiers while in operation. Screen with 12.7 mm square holes was placed in the uppermost position of the screen box. The covers were removed to permit photography. A sample of about 2 liters of chopped alfalfa was placed on this screen and the machine is started just before the camera was started

Table 2: mean percents and standard deviation for alfalfa silage (moisture content 56.2% w.b.)

Gyratory screen drive

Screen Number	Percent Retained on Screens							Std. Dev. S.D.	Pooled S.D (S_P)
	1	2	3	4	5	6	Mean		
4P	2.9	3.1	2.8	3.6	1.3	2.7	2.7	0.78	
3P	7.2	6.1	6.0	9.4	7.5	7.5	7.3	1.24	
2P	37.4	38.2	39.5	37.3	37.2	42.4	38.7	2.02	1.28
1P	39.6	39.3	39.2	37.4	41.6	36.4	38.9	1.82	
2S	9.9	10.3	9.6	9.5	9.8	9.2	9.7	0.38	
PAN	3.0	3.0	2.9	2.8	2.6	2.0	2.7	0.38	
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Linear screen drive

Screen Number	Percent Retained on Screens							Std. Dev. S.D.	Pooled S.D (S_P)
	1	2	3	4	5	6	Mean		
4P	3.2	2.2	2.4	5.5	3.2	2.9	3.2	1.18	
3P	9.2	9.6.	7.9	9.9	9.3	10.3	9.4	0.82	
2P	35.4	34.9	36.4	35.2	35.1	38.8	36.0	1.48	1.08
1P	39.5	40.3	40.3	37.1	40.0	37.3	39.1	1.49	
2S	9.7	9.6	9.8	9.3	10.0	8.6	9.5	0.50	
PAN	3.0	3.3	3.2.	3.0	2.4	2.0	2.8	0.51	
TOTAL	100.0	99.9	100.0	100.0	100.0	99.9	100.0		

Under-arc screen drive

Screen Number	Percent Retained on Screens							Std. Dev. S.D.	Pooled S.D (S_P)
	1	2	3	4	5	6	Mean		
4P	3.1	3.6	2.6	5.4	3.5	4.3	3.8	0.99	
3P	8.2	9.8	10.5	13.2	10.8	13.3	11.3	1.98	
2P	40.6	40.8	41.8	35.5	38.4	41.1	40.4	1.22	1.35
1P	35.7	34.1	34.1	31.5	36.4	32.0	34.0	1.94	
2S	9.0	8.6	7.8	7.4	8.3	7.8	8.2	0.59	
PAN	3.5	3.2	3.2	3.0	2.6	1.6	2.9	0.68	
TOTAL	100.1	100.1	100.0	100.0	100.0	100.1	100.3		

Table 2 (continued)

Over-arc screen Drive

Screen Number	Percent Retained on Screens							Std. Dev. S.D.	Pooled S.D (S_P)
	1	2	3	4	5	6	Mean		
4P	1.5	1.5	1.1	4.1	3.1	3.9	2.5	1.33	
3P	4.2	5.0	5.2	5.2	4.1	.5.3	4.8	0.54	
2P	39.2	39.2	39.2	39.5	36.5	43.2	39.5	2.14	1.66
1P	41.1	40.9	41.3	36.3	41.8	34.9	39.4	2.98	
2S	10.2	9.9	9.8	11.4	11.6	10.9	10. 6	0.78	
PAN	3.8	3.6	3.4	3.5	2.9	2.2	3.2	0.59	
TOTAL	100.0	100.1	100.0	100.0	100.0	99.9	100.0		

$$(S_P)^2 = (S.D.)\ 2/6$$

*Screen square hole sizes

4P 19.1mm (3/4in)

3P 12.7mm (1/2in)

2P 6.4 mm (1/4 in)

1P 3.2 mm (1/8 in)

2S 1.6 mm (1/16 in)

Table 3: mean percents and standard deviations for corn silage (moisture content 56. 9% w.b)

Gyratory screen drive

Screen Number*	Sample Percent Retained on Screen					Std. Dev. S.D.	Sample 2 Percent Retained on Screen					Std. Dev. S.D.
	1	2	3	4	mean		1	2	3	4	mean	
4P	2.6	2.5	2.6	1.3	2.3	0.64	0.6	0.5	1.1	0.9	0.8	0.28
3P	9.0	8.8	6.4	6.3	7.6	1.50	3.9	3.2	4.3	3.6	3.8	0.47
2P	49.9	53.25	3.95	5.0	53.0	2.20	53.7	51.2	54.4	54.1	53.4	1.46
1P	24.7	23.02	4.22	4.2	24.0	0.72	27.2	29.7	26.6	27.1	27.7	1.39
2S	9.2	8.2	8.7	9.0	8.8	0.43	10.1	10.7	9.2	10.4	10.1	0.65
PAN	4.7	4.3	4.2	4.2	4.4	0.24	4.4	4.7	4.4	3.8	4.3	0.38
TOTAL	100	100	100	100	100.1		99.9	100	100	99.9	100.1	

s_p+ =1.17 s_p+ = 0.91

Linear screen Drive

Screen Number*	Sample 1 Percent Retained on Screen					Std Dev S.D.	Sample 2 Percent Retained on Screen					Std Dev S.D
	1	2	3	4	mean		1	2	3	4	mean	
4P	2.8	1.2	2.5	3.0	2.4	0.81	0.6	0,7	0.7	1.3	0.8	0.32
3P	5.5	7.8	6.0	7.0	6.6	1.05	1.6	2.8	3.6	2.8	2.7	0.82
2P	47.5	52.7	51.5	54.5	51.6	2.97	48.8	48.9	50.4	56.1	51.1	3.45
1P	27.6	24.4	24.9	22.1	24.8	2.26	31.7	30.9	30.0	26.1	29.7	2.48
2S	10.3	9.0	9.8	8.6	9.4	0.77	11.3	11.2	10.3	9.2	10.5	0.98
PAN	6.3	4.8	5.3	4.7	5.3	0.73	6.0	5.6	5.0	4.5	5.3	0.66
TOTAL	100.0	99.9	100	99.9	100.1		100	100.1	100	100	100.1	

S_p+ = 1.67 s_p+ = 1.84

Under –arc screen Drive

Screen Number*	Sample 1 Percent Retained on Screen					Std Dev S.D	Sample 2 Percent Retained on Screen					Std Dev S.D
	1	2	3	4	mean		1	2	3	4	mean	
4P	2.6	2.8	4.7	2.6	3.2	1.02	0.4	1.7	1.7	1.2	1.3	0.61
3P	6.6	10.3	6.6	6.2	7.4	1.93	0.2	4.4	5.9	4.5	4.5	1.10
2P	48.9	52.3	50.6	54.3	51.5	2.31	46.4	49.3	55.9	57.6	52.3	5.32
1P	25.0	21.5	23.1	22.3	23.0	1.50	31.3	27.8	23.1	23.8	26.5	3.81
2S	10.9	8.4	9.7	9.3	9.6	1.04	12.8	10.9	8.5	8.4	10.2	2.11
PAN	6.0	4.7	5.4	5.3	5.4	0.53	6.0	5.9	4.9	4.6	5.4	0.70
TOTAL	100.	100	100.1	100	100.1		100.1	100.9	100	100.1	100.2	

s_p+ = 1.51 s_p+ = 2.87

Over-arc screen Drive

Screen Number*	Sample 1 Percent Retained on Screen					Std Dev S.D	Sample 2 Percent Retained on Screen					Std S.D Dev
	1	2	3	4	mean		1	2	3	4	mean	
4P	1.4	6.1	2.5	3.0	3.3	2.01	0.7	0.6	0.6	0.3	0.6	0.17
3P	3.8	8.8	9.1	4.1	6.5	2.89	2.3	1.8	3.3	2.5	2.5	0.62
2P	48.3	44.4	49.4	52.9	`48.7	3.50	47.1	45.2	53.5	42.2	47.0	4.78
1P	29.0	25.2	23.7	24.8	25.8	2.31	30.8	32.4	26.6	36.5	31.6	4.09
2S	10.6	9.3	9.5	9.5	9.7	0.59	11.9	12.4	10.4	12.2	11.7	0.91
PAN	6.9	6.3	5.8	5.7	6.2	0.55	7.1	7.6	5.7	6.2	6.7	0.86
TOTAL	100	100.1	100	100	100.2		99.9	100.4	100.1	99.9	100.1	

s_p+ = 2.26 s_p+ = 2.63

*screen square hole sizes

4P	19.1mm (3/4 in)
3P	12.1mm(1/2 in)
2P	6.4 mm (1/4 in)
1P	3.2 mm (1/8 in)
2S	1.17 mm (0.046 in)

5. Test Results

The results obtained from the three new oscillating classifiers were compared with those obtained from the John Deere Ottuma Works System [1].All the three new oscillating particle classifiers performed better than that developed at John Deere Ittuma Works when considering the pooled standard deviation. The classifiers with gyratory and linear motions generally had low standard deviation as shown in Tables 2 and 3.

The most repeatable results were obtained with the gyratory motion drive. visual observations of the films revealed that with the Under-Arc and Deere classifier forage material was tossed upwards near the stroke ends. Long particles often fell back onto the screen with their axes vertical thus allowing them to penetrate screens which should have retained them. Less of this action was noted with the linear and gyratory motion classifiers because their screens moved in a horizontal plane.

6.Calculation of Forage Chop Size

Particle size distribution is characterised by the parameters that measure the central tendency of the distribution and the dispersion about the central tendency. Most fine particle systems obey the logarithmic normal distribution function [4] This means that the distribution of the particle size itself when plotted in terms of per cent weight versus size is not normal but skewed. However, a transformation to the logarithm (base 10) of the particle sizes gives a normal distribution, the mean, median and mode coincide and have identical values. The single central tendency value is the geometric standard deviation (s_{gw}). The two values completely define the log-normal particle size distribution. Thus the geometric mean length and geometric standard deviation of the samples tested were obtained from equations (1) and (2).

Equations (1) and (2) are similar to those used in determining the particle size of feed materials by sieving [5] and are based on the assumptions that forage weight distribution data are logarithmic normally distributed.

$$\times_{gw} = \log -1\left(\frac{\sum(w_i log \overline{\times}_i)}{\sum w_i}\right) \quad (1)$$

$$s_{gw} = \log -1\left(\frac{\sum w_i(log \overline{\times}_i - \log \times_{gw})^2}{\sum w_i}\right)^{1/2} \quad (2)$$

Where

X_{gw} = geometric mean length

w_i = Weight fraction on the i^{th} screen

$\overline{X}_i$ = geometric mean length of particle on the i^{th} screen

$= (x_i + x_i + 1)1/2$ (3)

x_i = diagonal of screen opening of the i^{th} screen

$x_i + 1$ = diagonal of openings in next larger than i^{th} screen (just above in set)

s_{gw} = geometric standard deviation.

The geometric mean length and geometric standard deviation as calculated using equations (1) and (2) for chopped alfalfa at 59.9% moisture (wb) were 7.13 mm and 1.89 respectively.

Graphical solutions for geometric mean length and geometric standard deviation are obtained by plotting the results on logarithmic normal probability paper as show in Figure 2. From Fig 2 the geometric mean length was 5.9 mm and the geometric standard deviation was 1.81. These values compare favourably with those obtained from using equations (1) and (2).

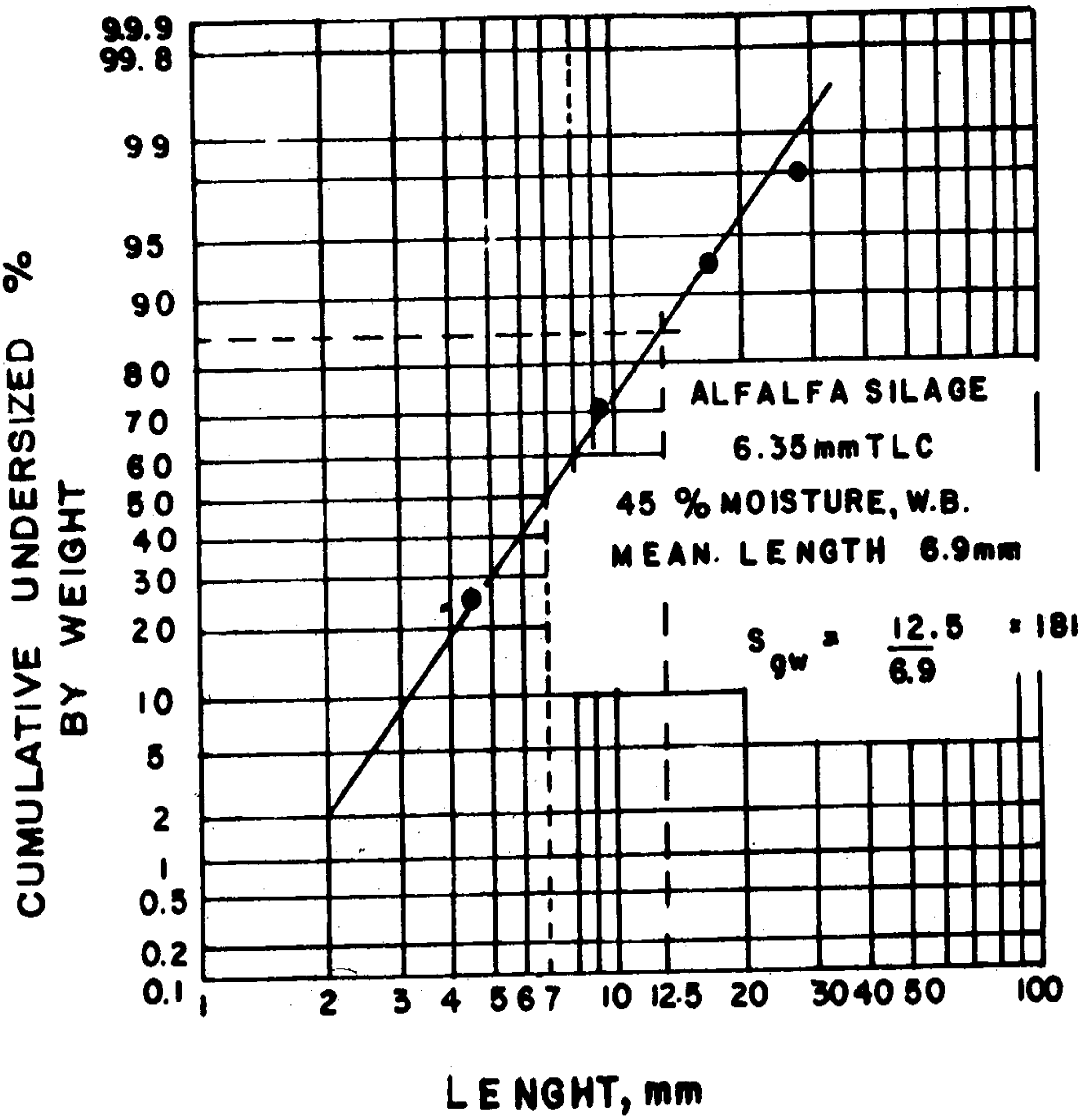

Fig.2. cumulative percent undersized particles versus screen opening size for alfalfa.

7. Summary.

The dairy animal does need palatable high quality feed. Length of cut affects fermentation which in turn affects palatability and quality. Since a good fermentation can only result if air is excluded from the forage during the fermentation process, the length of cut needs to be adjusted to aid in packing the forage into the silo.

The Nigerian forage industry has been faced with problems of conservation and vacuum silos have been advocated for our level of forage production [6]. The success of such silos is dependent on the forage particle size. Short cuts will not only improve the capacity of such silos, but may reduce the intrusion of air into the mass of forage and affords greater ease in the removal of air during the fermentation process.

The classifiers developed will provide accurate and adequate forage particle size for the vacuum silos

CONCLUSIONS

1. The three oscillating classifiers developed performed better than that developed at John Deere Ottuma Works.
2. The classifier with gyratory motion, generally had the least standard deviation and the most repeatable results.
3. The under-arc and the Deere classifier tossed chopped forage upwards towards their stroke ends, thus permitting particles to penetrate screen which would have otherwise retained them.
4. The used of equations (1) and (2) for calculating the geometric mean length and geometric standard deviation of chopped forage materials provides an alternative way of obtaining fast results other than the graphical solutions

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