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Linguistic and Machine Methods for Compiling and Updating the Harvard Automatic Dictionary

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Natural languages, unlike some abstract linguistic systems studied by mathematical logicians or some instruction codes devised by designers of automatic programming systems, have no easily described simple structure. Considerable empirical study is therefore necessary to develop for these languages grammars that are sufficiently precise and comprehensive to serve as the basis for any system of automatic translation. The difficulty of such empirical study is attested to by the almost total absence, after nearly a decade of interest in automatic translation, of any but theoretical discussions of the subject. The empirical work that has been reported is generally the result of laborious manual work and, even where machines have been used, results are based on such limited and carefully selected samples that their significance is doubtful.

Significant research on automatic translation presents such massive data handling problems that, unless automatic machines and associated techniques are used as tools to assist in research from the beginning, chaos is a likely result. Research workers with both adequate qualifications in linguistics and experience in the design and operation of automatic information processing machines are relatively scarce. Careful planning is therefore essential in order to enable the performance of large scale routine tasks by a team of clerical and technical personnel assisted by automatic machines. The necessary automatic machines are presently available in the form of general purpose digital calculators. By the application of present techniques of automatic programming, and by the development of new ones, much of the programming of these cal-

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culators can systematically be reduced to routine processes to be performed by clerical personnel or even by the machine itself.

While enough is already known about automatic translation and allied problems to warrant paying attention to the development of suitable input, output, and storage devices, the processes of translation are hardly well enough defined yet to justify the construction of a complete specially designed translating system. General purpose machines can provide adequate algorithmic power and sufficient storage capacity with a minimum of capital outlay. Different methods can readily be tested merely by writing different programs, suggesting a method of successive approximations, whereby the results of experimental operation of the system up to a given time can be used to improve the mode of operation for future time. Whenever possible, it is desirable to make program modification itself a part of automatic machine functions. In this fashion optimal design parameters for special equipment can eventually be determined. For a variety of field applications, general purpose machines may well continue to be used even for production, although it is likely that the efficient and economical operation of large translation centers will eventually require the use of specially designed equipment.

With these premises in mind, the work described in this paper has been centered on the formulation and practice of efficient techniques for the initial compilation and periodic up-dating of automatic dictionaries. The first Harvard Automatic Dictionary is intended primarily to provide the following three facilities: *(a)* an immediately useful device for lightening the burden on professional translators, speeding up their work, and improving its accuracy and timeliness; *(b)* a system of automatic word-by-word translation, serving as a linear first approximation to an automatic translation system; *(c)* an experimental tool to facilitate the extensive basic research still necessary to develop methods for faithful smooth translation of technical Russian into English.

While automatic translation from Russian to English is the specific object of our research, automatic dictionaries and the techniques for compiling them lend themselves to more general applications, including translation between other pairs of languages, and certain phases of information organization and retrieval. Automatic abstracting, by techniques such as described by Luhn (1), is one example of such an application. An automatic dictionary in which a record is kept of the frequency of use of each entry can provide an accurate and current standard for eliminating the “noise” caused by words common in any text. The inverse inflection algorithm mentioned in Section 2, extended if desirable to account for derivation as well, can be useful in mapping inflectional variants of a stem, or derivatives of a root, into a single class or canonical form. When the source text is in a foreign language, combining automatic abstracting with automatic translation of the abstract is an obvious possibility. In searching texts for the occurrence of key words or word combinations, the use of inverse inflection and derivation algorithms will permit specifying keys in a canonical form, with the guarantee that occurrences of inflected or derived variants will also be detected. As the translation algorithms based on the use of automatic dictionaries grow in sophistication, the ties between automatic language translation and the many areas where syntactic analysis and code conversions are necessary will very likely continue to be strengthened.

1. Word selection

In planning for dictionary compilation, efforts were made to minimize the need for manual intervention, to retain flexibility for experimental purposes, and to provide procedures suitable for periodic up-dating of operating dictionaries, as well as for their initial compilation.

The initial selection of entries for a dictionary can be carried out by two major processes, each having peculiar advantages and disadvantages. The first method may be likened to panning for gold. In this method some number of texts of the type eventually to be translated are scanned, and a glossary of all distinct forms occurring in this sample is compiled. The main advantage of the method is that every form obtained in this way is in current use, and therefore is a suitable candidate for inclusion in a glossary. If scanning is to be performed automatically, the texts must necessarily be transcribed onto some automatically readable medium, hence made available for other purposes, including the eventual testing of translation methods. The major disadvantage of the procedure is that it becomes progressively less and less productive. While nearly all the first few words of the first text scanned are likely to be nuggets, as the work progresses more and more gravel must be handled before another nugget is found. Relatively few word forms account for the vast majority of form occurrences in any text; these forms are found over and over again and must be rejected over and over again. Second, in pure panning, only those particular inflected forms of any word that actually occur in the sample under study will be entered in the glossary. Until all the forms constituting the paradigm of a word have occurred in some text, a complete characterization of this word is not available. This precludes the possibility of early systematic treatment of inflectional processes, other than by handling each inflected form as a unique entity.

The second approach may be called the “fish net” method. Available dictionaries are dragged for words useful according to some reasonable criterion. Anything caught in the net is retained. The chief advantage of this procedure is that a large selection of useful words is obtained very rapidly. The major disadvantage is that the resulting dictionary is only as good as the criterion of selection or as the dictionaries from which it was selected. Moreover, words without current utility may well be caught in the net.

Neither method is guaranteed to yield a vocabulary precisely suitable for the first texts to which a dictionary is applied, but either lends itself to the addition of new words or new forms whenever these appear in a text. How rapidly the ratio of text words not in the dictionary to those in it will diminish to a satisfactory level is still open to conjecture. For that matter, so is a satisfactory definition of this level.

The procedure described here is a combination of the two methods. An initial set of nearly ten thousand words was selected, in part, from a general dictionary (2) to obtain words of common currency and, in part, from a specialized electronics dictionary (3) to obtain as complete as possible a coverage of technical terms in this area. In cases of doubt about the utility of words, they were usually included. It seems more efficient to carry a few doubtful words through routine compilation procedures and to provide for their automatic removal (based on a criterion of frequency of use), once operating experience has accumulated, than to spend valuable personnel time on intricate and inconclusive selection procedures. Once the dictionary is functioning, all new words encountered in texts submitted for translation, but not in the dictionary, will be printed as a by-product of dictionary operation. These new words, from text sources, will eventually replace the initial stock as the raw material for an up-dating procedure almost identical to the compilation process. For up-dating, therefore, the fish net process is replaced by a modified gold panning technique, where the gravel is the major object of processing, and the gold a valuable, but easily obtained by-product; prior to further processing, each new form found in a text is reduced to the form normally listed in dictionaries. The accumulation of frequency data, the analysis of contexts and other analytic procedures can be carried out on texts already recorded in automatically readable form because of their interest as objects of translation.

2. The form of dictionary entries

In ordinary dictionaries, the paradigm of a word is conventionally represented by a standard or “canonical” form, e.g., the nominative singular for nouns, the nominative masculine singular for adjectives, and the infinitive for verbs. This lexicographic device presupposes on the part of a person using the dictionary the ability to perform the grammatical analysis necessary to reduce an inflected form of a word found in a text to the canonical form listed in the dictionary. As conventionally practiced, this grammatical analysis requires a fairly thorough acquaintance with the inflection system of the language in question, as well as a certain amount of imagination.

An automatic dictionary may provide for the treatment of inflected forms either (*a*) by providing a distinct entry for each distinct inflected form or (*b*) by providing only a single canonical form as an entry for each word, together with an algorithm for transforming other forms to the canonical one. A variety of compromises between these two extremes is also possible. Whichever type of entry is used, if words are selected from existing dictionaries by the fishing technique, an algorithm capable of generating all distinct inflected forms of every word given in the conventional canonical form is essential. The need is obvious if a distinct entry is to be made for each distinct inflected form. Under circumstances described further on, the generation of all distinct inflected forms is useful even if only the canonical forms are to be used as dictionary entries. The pure gold panning procedure by-passes these difficulties, but at the price of commitment to the system of distinct entries for distinct inflected forms.

If experimental work is to be carried out on existing machines, facilities sufficiently ample and economical to store a large dictionary are presently available only in the form of magnetic tapes or punched cards. Because using distinct inflected form entries would increase storage requirements and search time by an order of magnitude, this method will be practicable only when large capacity internal memory devices with sufficiently low cost and access time become available (4,5). Certainly for the present, and probably for the future, the use of canonical form entries seems indicated.

The canonical form chosen for our purposes is best described as a "stem," because its definition is very close to that of stems as commonly defined by linguists. The precise definition of stems and a description of the algorithm used for reducing arbitrary members of a paradigm to this canonical form have been given earlier (6). The reduction algorithm or "inverse inflection algorithm" cuts forms into two parts, one, the stem, the other, an ending usually identical with or at least very similar to the usual Russian inflectional desinences. When the dictionary is in operation, each form occurring in a text is split by the inverse inflection algorithm into a stem and an ending. The stem is used as the key for search in the dictionary, and the ending is retained for eventual use in syntactic analysis. To insure that the stems produced by splitting text forms will be identical with stems entered in the dictionary, the latter are obtained by applying the inverse inflection algorithm to all members of the paradigm of any word about to be entered in the dictionary.

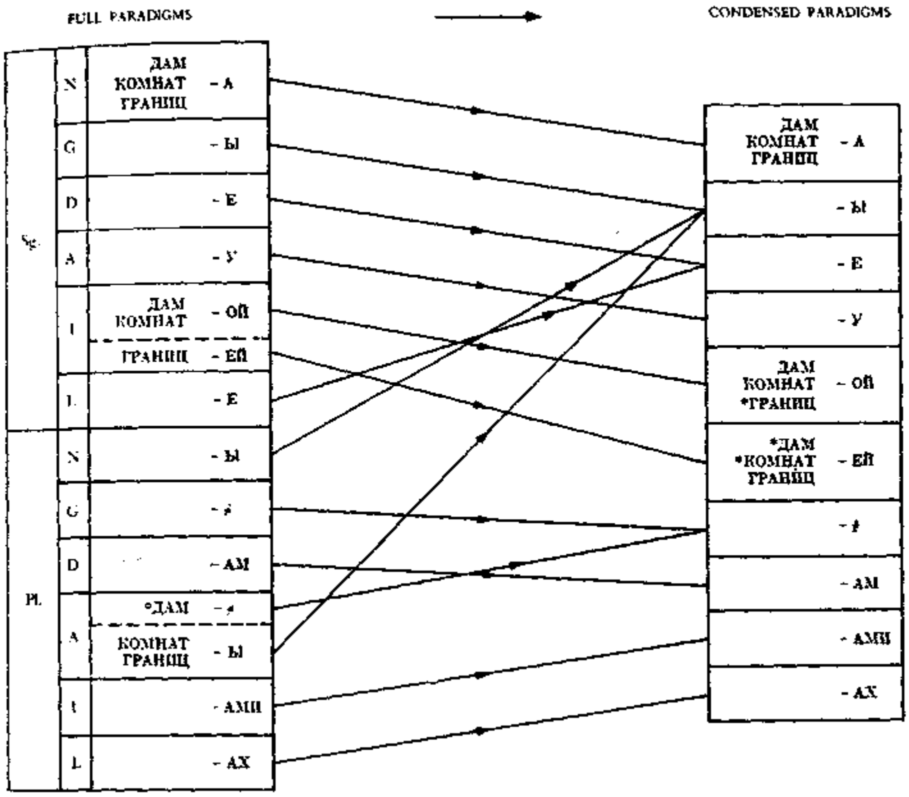
3. *The generation of paradigms*

Generating all inflected forms belonging to the paradigms of ten thousand canonical forms obtained from standard dictionaries is a task not to be undertaken lightly. As a purely manual operation, this task would be staggering, and the probability of errors extremely high. The standard Russian noun paradigm has twelve forms, the adjective paradigm twenty-four or twenty-eight forms, and verbs have well over one hundred forms, if participles are counted. Because not all members of every paradigm are distinct (e.g., the nominative singular form of some nouns is identical with the accusative singular form), it is sufficient to generate a "condensed paradigm," containing only distinct inflected forms. However, even the number of distinct inflected forms is enormous.

In Russian, inflected forms are characterized by their desinences, so that the specification of a paradigm is tantamount to specifying a type of arrangement of inflectional desinences. While the morphological differentiation of word stems is great, that of inflectional desinences is relatively small. The inflection pattern of one word can therefore be used to obtain the inflected forms of all other words characterized by the same nature and disposition of inflectional desinences. This suggests the possibility of developing an algorithm for automatic direct inflection, which will treat alike all words identified as having identical or sufficiently similar inflection patterns.

A new system of classification was therefore developed (7) such that, once a word has been identified as belonging to a class whose members are inflected in a certain way, it can be inflected automatically. Classification systems given in existing grammars were found to be both incomplete and often incompatible with our requirements. Our system of classification is based on the assumption that the identification of the inflectional pattern of a word must, for the time being at least, remain a manual function, while the actual generation of distinct inflected forms can be an almost completely automatic process. Therefore, ease and accuracy of identification must be promoted by using any readily obtainable data meaningful to a person, while the generation must be based strictly on explicit orthographic data recognizable by a machine.

Some of the criteria used in defining classes may be illustrated with reference to Fig. 1. The first column of Fig. 1 describes the full paradigms of the Russian words дама, комната, and граница. Condensed paradigms, where only distinct inflected forms appear, are illustrated in the second column. It will be noted that дама and комната have been included in the same class, even though they differ in the accusative plural, because their condensed paradigms



°MARKS THE FORM OF AN ANIMATE NOUN DIFFERING FROM ITS INANIMATE COUNTERPART.
*MARKS A SPURIOUS DISTINCT INFLECTED FORM.

FIGURE 1. Condensation of paradigms (examples drawn from class N4).

can be generated by identical procedures. The justification for including граница in this class is twofold: first, differentiating граница from комната is inefficient at this stage and is accomplished more readily at a stage described in Section 4. Second, the only price to be paid for simplifying classification in this way is the addition of a spurious inflected form to the paradigm of each member of this class. This addition is harmless. If a dictionary of distinct inflected forms is being compiled, the spurious forms will never be consulted and therefore will eventually be eliminated by virtue of their zero frequency of use. In a dictionary of canonical form stem entries, a spurious form usually leaves no traces, since it leads to a stem identical to those obtained from the other distinct inflected forms. This procedure is very much like one used quite frequently in approximating mathematical functions over a given range: any convenient function may be used that suitably approximates the desired function in the specified range; its behavior outside of this range is of no consequence. Other expedients of this kind are also proving their worth in terms of greater systematization than would be possible without them. As those experienced in automatic data processing well know, the handling of a single exceptional case often proves more costly and more time-consuming than the routine handling of a few extra elements.

The definitions of inflectional classes and the rules for forming distinct inflected forms of words belonging to these classes are illustrated in Fig. 2. The characteristics identifying a class are given under (I) and the process of inflection is described under (II). It will be noted that all structural operations to be performed in the process of automatic inflection, or the phenomena bearing upon them, are described strictly in terms of orthography. For example, in the class N4, the set of distinct inflected forms is described as consisting of the standard dictionary canonical form, plus several other forms generated by adding specified endings to a generating stem. The rule of formation for the generating stem itself is given in such terms as "canonical form minus last letter." The generating stems defined in the formation rules for distinct inflected forms are not necessarily identical with the stems that will be used as entries for the dictionary. The latter are obtained by applying the inverse inflection algorithm

N4. дама, лампа, игла, служба

I. A class ending in -a preceded by any consonant except:
(i) г, ж, к, х, ч, ш, щ,
(ii) ц, whenever preceded by another consonant;
(iii) the majority of cases when the consonant is л, н,
(iv) some cases when the consonant is м, р,
(v) a few cases when the consonant is б,
} preceded by another consonant

II. Formation roles for distinct inflected forms:
(i) Generating stem = canonical form[a] - last letter;
(ii) Distinct inflected forms:

(a) canonical form
(b) generating stem + ы
(c) + е
(d) + у
(e) + ой
(f) generating stem + ей
(g) + #
(h) + ам
(i) +ами
(j) +ах

N4.31 вышлавка, кишкá

I. A "reappearing o" class embracing the nouns ending in -a preceded by:
(i) any consonant (except й, ж, ш, ч, ц), not followed by ь, + к;
(ii) ж, ш, ч, + к, whenever the stress falls upon the ultima of the word;

II. Formation rules for distinct inflected forms:
(i) Generating stem = canonical form - last letter, but an o must be inserted between the penult and the ultima of the generating stem in (g);
(ii) Distinct inflected forms as in N4, II (ii), except -и for -ы in (b).

[a] The canonical form here is that used in standard dictionaries, not the "stem" canonical form used in the Automatic Dictionary.

FIGURE 2. Rules for class identification and inflection.

to the distinct inflected forms, and the resulting canonical stems are not always identical with the generating stems. For example, the past passive participial forms of some verbs are constructed most readily by adding -енный to a generating stem. The canonical stem of the corresponding paradigm includes the letters -енн.

Because the assignment of words to classes is intended, for the present, to be a manual task, any classification criterion that is easily recognized by persons can be used. For example, stress distinctions, which cannot be used in defining formation rules, serve as a means of class identification. In addition, significant examples, lists of exceptions, and so forth, have been given wherever possible.

Our system also embraces a large number of words whose formation is "irregular." For example, the class N4.31 comprises words in which the vowel "o" is introduced in one inflected form. The formation rules for this class (Fig. 2) therefore specify that an "o" must be inserted between the last and next to the last letters of the generating stem before constructing the form (g). The class N4.31 is further distinguished from the class N4 by the use of the letter и for the letter ы in the inflected form (b). Whenever the formation rules for one class deviate only slightly from those for another class, they have been stated as exceptions to the rules for this other class. Considerable economies in programming inflection are achieved as a result.

Our system of classification comprises eight classes of adjectives, thirty-eight classes of nouns, and forty-six classes of verbs. Indeclinable words are assigned to a special class. The system of classification is sufficiently comprehensive to include all but a few unproductive classes with highly atypical paradigms; it is completed by the definition of a class, labeled Z99.99, to which all words not falling into any of the other classes are assigned. These words are eventually inflected by hand. Of a total of seventy-six hundred words classified to date, all but twenty-four were assigned to genuine classes. The distribution of these words among the major groupings is indicated in Fig. 3.

Total number of:

Adjectives	2477	32.59
Nouns	3972	52.26
Invariables	74	0.97
Unclassified nouns and adjectives (Z99.99)	13	0.17
Verbs	1053	13.86
Unclassified verbs (Z99.99)	11	0.14
Total	7600	99.99

FIGURE 3. Distribution of words among major groups.

The class definitions as given in Fig. 2 are not in a form that readily lends itself to rapid recognition. To make classifying as easy as possible, the rules were expressed in a tabular form (3) illustrated in Fig. 4, where the complete classification table for adjectives is displayed. The vertical lines in Fig. 4 divide endings on the right from significant terminal stem letters on the left. The special symbols C, V, and $C_ьC$ are interpreted as follows: C denotes any consonant not specified earlier in the group between horizontal lines, and V the same for vowels. The combination $C_ьC$ signifies any consonant, whether; followed or not by the soft sign, and not specified earlier within the group. For example, an adjective ending in -ий preceded by к may be assigned to any of the classes A6, A7, or A8, depending on the letter preceding к. If the letter preceding к is one of the three indicated next to A7, the adjective is assigned to this class, if the letter preceding к is any consonant not in the list belonging to A7, the adjective is assigned to the class A6, and finally, if the letter preceding к is any vowel, the adjective is assigned to the class A8. Vowel changes are marked by the sign >. On the left side of the sign is the vowel before the change, and on the right side the vowel after the change. For example, in the third group in Fig. 4 adjectives ending in -ый preceded by л or р are normally assigned to the class A3, unless the vowel е is inserted as the second letter from the end in the masculine predicative form of the adjective. Through the use of these charts, assigning to classes becomes a routine task which can be done by a person with relatively little knowledge of Russian, although occasionally dictionaries must be consulted in the process. Experience has shown that the amount of dictionary consultation at this stage is negligible. With this one exception, all inevitable dictionary consultation is concentrated at a single stage of the process, namely, when English correspondents are assigned and grammatical codes are added to the stems. Assigning words to classes has been successfully done at an average rate of approximately one thousand words per day per person.

4. The preparation of stem entries

Because our dictionary is intended for operation on the Univac I computer at the Harvard Computation Laboratory, some details of the preparation of stem entries and of other phases of compiling apply directly only to this machine. However, very similar procedures can be readily used with other types of contemporary large-scale computers.

Words selected from the two dictionaries mentioned earlier were originally transcribed onto file cards. An inflectional class marker, assigned in the manner outlined in Section 3, was then written on each card. The card file is used only in the initial compilation process, since new words found in texts as a by-product of dictionary operation will be made available automatically in a

ADJECTIVES

				1
	ш ж ч щ	ий ий ий ий	A4	
	н	ий	A5	
	г х	ий ий	A8	
C ----------------------->	жк йк ьк	ий ий ий	A7	
C ---------------------- >	к	ий	A6	
V ---------------------- >	к	ий	A8	
				2
	ж к ш г х	ой ой ой ой ой	A8	
(C_bC)------------------->	н	ой	A2	
V ---------------------->	н	ой	A3	
C ----------------------->		ой	A3	
				3
	нн	ый	A1	
(C_bC) ------------------->	н	ый	A2	
V ---------------------- >	н	ый	A3	
	л р	ый ый	A3 but A2 if masculine predicate: ø > e_2	
C ---------------------- >		ый	A3	

FIGURE 4. Classification table for adjectives.

printed format suitable as raw material for the periodic dictionary up-dating.

Classified words are next recorded on magnetic tapes by means of a standard Unityper. Because this input device is designed to handle normally only numerals, the Roman alphabet, and a few special characters, some adaptation was necessary to use it for typing Cyrillic material. The set of characters used for this purpose is shown in column 1 of Fig. 5. It is a fairly simple matter to place over the normal keys of any typewriter special keytops engraved with any desired alphabet. We chose to arrange the keyboard in one of the standard Cyrillic layouts, to ease the work of typists already familiar with it. The correspondence so established between Cyrillic and machine characters is described by columns 1 and 2 of Fig. 5. Although this correspondence preserves a familiar layout, it does not preserve normal Cyrillic alphabetic order, and alphabetization of words in the code of column 2 is impossible. Magnetic tapes obtained from the typewriter are therefore used as input to a code conversion run in which the typewriter code of column 2 is converted into the ranked code given in column 3. The correspondence between Cyrillic characters and machine characters becomes that given between columns 1 and 3. The ranked code of column 3 is used throughout compilation and up-dating as well as throughout the dictionary look-up operations. Russian material re-

UNIVAC Codes for Cyrillic Alphabet

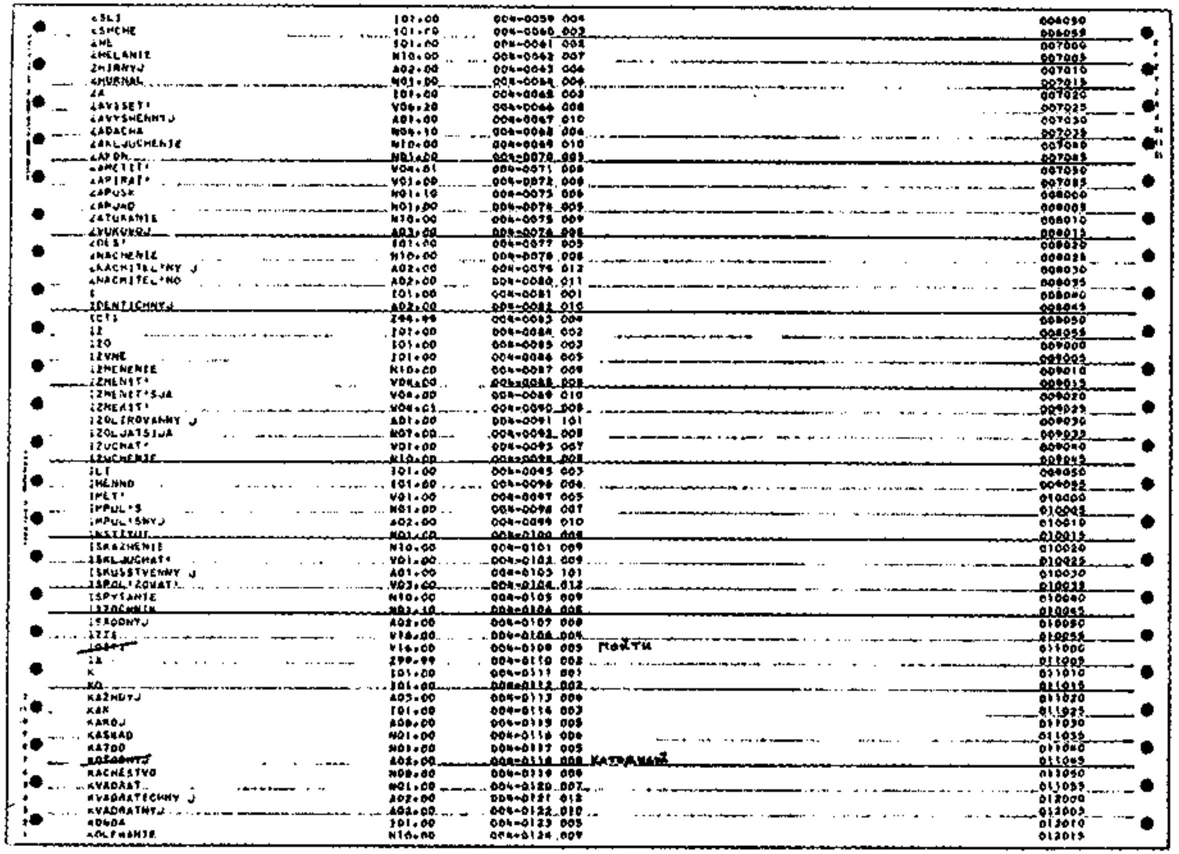
1	2	3	4	1	2	3	4	1	2	3	4
0	0	,	0	З	O	8	Z	Ш	U	R	SH
1	1	&	1	И	B	9	I	Щ	I	+	SHCH
2	2	r	2	Й	Q	;	J	Ъ	г	S	#
3	3	A	3	К	E	B	K	Ы	S	T	Y
4	4	F	4	Л	K	C	L	Ь	M	U	'
5	5	¢	5	М	V	D	M	Э	&	V	EH
6	6	@	6	Н	T	E	N	Ю	.	X	JU
7	7	t	7	О	J	G	O	Я	Σ	Y	JA
8	8	/	8	П	G	H	P	Δ	Δ	Δ,0	Δ
9	9	J	9	Р	H	I	R	(	(	(	(
А	F	1	A	С	C	)	S	#	#	#	)
Б	,	2	B	Т	N	K	T	”	”	”	;
В	D	3	V	У	W	L	U	$	$	$	:
Г	Y	4	G	Ф	A	M	F	*	*	*	*
Д	L	5	D	Х	P	N	X	.	+	.	.
Е	R	6	E	Ц	-	P	TS	,	|	,	,
Ж	;	7	ZH	Ч	X	Q	CH	%	%	%	-

1: Cyrillic Available on Keyboard
2: Typewriter Code
3: Ranked Code
4: Transliteration Code

FIGURE 5.

corded in the ranked code obviously cannot be easily read, so that material which must be read quickly is subjected to still another code conversion run in which the character strings given in column 4 of fig. 5 are substituted for their correspondents in column 3. Eventually, the conversion from the code of column 1 to that of column 3 will be made simultaneous with typing.

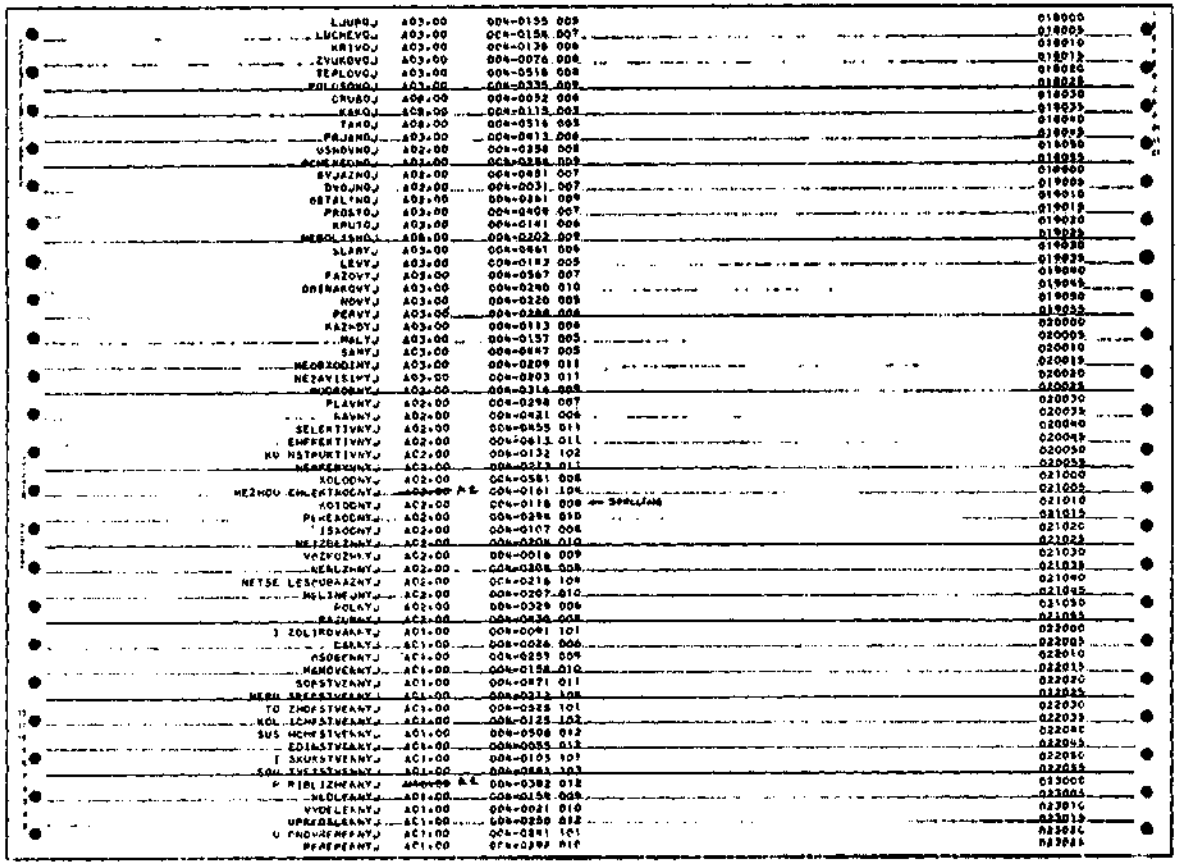
Two lists are prepared from the tape recorded on the typewriter. The first, illustrated in Fig. 6, presents the words in the order in which they were typed



ESLI	I07.00	004-0059 004		006050
ESHCHE	I01.00	004-0060 003		006055
ZHE	I01.00	004-0061 002		007000
ZHELANIE	N10.00	004-0062 007		007005
ZHIDKIJ	A02.00	004-0063 006		007010
ZHURNAL	N01.00	004-0064 006		007015
ZA	I01.00	004-0065 002		007020
ZAVISET'	V06.20	004-0066 008		007025
ZAVYSHENNYJ	A01.00	004-0067 010		007030
ZADACHA	N04.10	004-0068 006		007035
ZAKLJUCHENIE	N10.00	004-0069 010		007040
ZAKON	N01.00	004-0070 005		007045
ZAMETIT'	V04.01	004-0071 008		007050
ZAPIRAT'	V01.00	004-0072 008		007055
ZAPUSK	N01.10	004-0073 006		008000
ZARJAD	N01.00	004-0074 005		008005
ZATUXANIE	N10.00	004-0075 009		008010
ZVUKOVOJ	A03.00	004-0076 008		008015
ZDES'	I01.00	004-0077 005		008020
ZNACHENIE	N10.00	004-0078 008		008025
ZNACHITEL'NYJ	A02.00	004-0079 012		008030
ZNACHITEL'NO	A02.00	004-0080 011		008035
I	I01.00	004-0081 001		008040
IDENTICHNYJ	A02.00	004-0082 010		008045
ICTI	299.99	004-0083 004		008050
IZ	I01.00	004-0084 002		008055
IZO	I01.00	004-0085 003		009000
IZVNE	I01.00	004-0086 005		009005
IZMENENIE	N10.00	004-0087 009		009010
IZMENIT'	V04.00	004-0088 008		009015
IZMENIT'SJA	V04.00	004-0089 010		009020
IZMERIT'	V04.01	004-0090 008		009025
IZOLIROVANNYJ	A01.00	004-0091 101		009030
IZOLJATSIJA	N07.00	004-0092 008		009035
IZUCHAT'	V01.00	004-0093 007		009040
IZUCHENIE	N10.00	004-0094 008		009045
ILI	I01.00	004-0095 003		009050
IMENNO	I01.00	004-0096 006		009055
IMET'	V01.00	004-0097 005		010000
IMPUL'S	N01.00	004-0098 007		010005
IMPUL'SNYJ	A02.00	004-0099 010		010010
INSTITUT	N01.00	004-0100 008		010015
ISKAZHENIE	N10.00	004-0101 009		010020
ISKLJUCHAT'	V01.00	004-0102 009		010025
ISKUSSTVENNYJ	A01.00	004-0103 101		010030
ISPOL'ZOVAT'	V03.00	004-0104 012		010035
ISPYTANIE	N10.00	004-0105 009		010040
ISTOCHNIK	N01.10	004-0106 008		010045
ISXODNYJ	A02.00	004-0107 008		010050
ITTI	V16.00	004-0108 004		010055
~~[illegible]~~	V16.00	004-0109 005	ПОЙТИ	011000
IX	299.99	004-0110 002		011005
K	I01.00	004-0111 001		011010
KO	I01.00	004-0112 002		011015
KAZHDYJ	A05.00	004-0113 006		011020
KAK	I01.00	004-0114 003		011025
KAKOJ	A06.00	004-0115 005		011030
KASKAD	N01.00	004-0116 006		011035
KATOD	N01.00	004-0117 005		011040
~~[illegible]~~	A02.00	004-0118 008	КАТОДНЫЙ	011045
KACHESTVO	N08.00	004-0119 008		011050
KVADRAT	N01.00	004-0120 007		011055
KVADRATICHNYJ	A02.00	004-0121 012		012000
KVADRATNYJ	A01.00	004-0122 010		012005
KOGDA	I01.00	004-0123 005		012010
KOLEBANIE	N10.00	004-0124 009		012015

Figure 6. Alphabetized word list.

and is used for catching errors made in typing the words; it will eventually be replaced by hard copy made by the typewriter itself. The other, shown in Fig. 7, is alphabetized by the last letters of words rather than by the first as usual, and justified to the right to bring all words with like endings together. It is used to check the classification of words. Because the criteria for classification are based largely on the configuration of the last letters of each word, words with the same class marker tend to be brought together on this list.



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            LUCHEVOJ    A03.00      004-0158 007    018005
              KRIVOJ    A03.00      004-0138 008    018010
            ZVUKOVOJ    A03.00      004-0076 008    018015
            TEPLOVOJ    A03.00      004-0518 008    018020
           POLUSONOJ    A03.00      004-0335 009    018025
              GRUBOJ    A08.00      004-0052 004    018030
               KAKOJ    A08.00      004-0115 003    018035
               TAKOJ    A08.00      004-0516 003    018040
            PRAJANOJ    A03.00      004-0413 006    018045
            OSNOVNOJ    A02.00      004-0358 008    018050
          [illegible]   A02.00      004-0288 009    018055
            SVJAZNOJ    A02.00      004-0481 007    019000
             DVOJNOJ    A02.00      004-0031 007    019005
           OSTALNOJ     A03.00      004-0361 009    019010
             PROSTOJ    A03.00      004-0409 007    019015
              KRUTOJ    A03.00      004-0141 006    019020
           NEBOLSHOJ    A08.00      004-0202 009    019025
              SLABYJ    A03.00      004-0461 006    019030
               LEVYJ    A03.00      004-0183 005    019035
             FAZOVYJ    A03.00      004-0567 007    019040
          ODINAKOVYJ    A03.00      004-0290 010    019045
               NOVYJ    A03.00      004-0220 005    019050
              PERVYJ    A03.00      004-0288 006    019055
             KAZHDYJ    A03.00      004-0113 006    020000
               MALYJ    A03.00      004-0157 005    020005
               SAMYJ    A03.00      004-0447 005    020010
         NEOBXODIMYJ    A03.00      004-0209 011    020015
         NEZAVISIMYJ    A03.00      004-0203 011    020020
          [illegible]   A03.00      004-0314 009    020025
             PLAVNYJ    A02.00      004-0298 007    020030
              RAVNYJ    A02.00      004-0421 006    020035
         SELEKTIVNYJ    A02.00      004-0455 011    020040
        EHFFEKTIVNYJ    A02.00      004-0613 011    020045
     KO NSTRUKTIVNYJ    AC2.00      004-0132 102    020050
          [illegible]   AC2.00      004-0213 011    020055
            XOLODNYJ    A02.00      004-0581 008    021000
MEZHDU EHLEKTRODNYJ   ~~A02.00~~ A2 004-0161 104    021005
            KATODNYJ    AC2.00      004-0118 008 ← SPELLING    021010
          PEREXODNYJ    A02.00      004-0294 010    021015
            ISXODNYJ    A02.00      004-0107 008    021020
          NEIZBEZHNYJ   AC2.00      004-0208 010    021025
           VOZMOZHNYJ   AC2.00      004-0016 009    021030
          [illegible]   A02.00      004-0305 008    021035
NETSE LESOOBRAZNYJ      A02.00      004-0216 104    021040
           NELINEJNYJ   AC2.00      004-0207 010    021045
              POLNYJ    A02.00      004-0329 006    021050
          [illegible]   AC2.00      004-0430 008    021055
      I ZOLIROVANNYJ    A01.00      004-0091 101    022000
              DANNYJ    AC1.00      004-0026 006    022005
           OSOBENNYJ    AC1.00      004-0253 009    022010
          [illegible]   AC1.00      004-0158 010    022015
         SOBSTVENNYJ    AC1.00      004-0471 011    022020
          [illegible]   AC1.00      004-0313 108    022025
     TO ZHDESTVENNYJ    AC1.00      004-0528 101    022030
    KOL ICHESTVENNYJ    AC1.00      004-0125 102    022035
    SUS HCHESTVENNYJ    A01.00      004-0506 012    022040
         EDINSTVENNYJ   AC1.00      004-0055 012    022045
      I SKUSSTVENNYJ    AC1.00      004-0103 103    022050
          [illegible]   A01.00      004-0083 103    022055
      P RIBLIZHENNYJ  ~~A01.00~~ A1 004-0382 012    023000
          [illegible]   A01.00      004-0158 009    023005
          VYDELENNYJ    A01.00      004-0021 010    023010
         UPRAVLENNYJ    AC1.00      004-0250 012    023015
          [illegible]   AC1.00      004-0341 101    023020
          PEREMENNYJ    AC1.00      004-0397 010    023025
```

FIGURE 7. End alphabetized word list.

Checking class markers is facilitated by the presence of runs of identical class markers, in which the occurrence of an odd marker shows up clearly. Errors detected on these lists are not corrected on tape. It is easier to delete the affected items prior to assigning correspondents to them, and then to process them again in routine fashion with another batch. Therefore, items found in error are simply marked for deletion at the later stage.

Throughout compilation (8), Russian words represented in the ranked code are imbedded in “items” consisting of five machine words of twelve characters each. The first three machine words are used to store the Russian word, allowing a maximum of thirty-six letters. The first six character positions of the fourth word of each item are reserved for the inflectional class marker as shown in Figs. 6 and 7. Eight positions in the fifth word are used for an identification number which designates the batch in which the word was originally processed, and the serial number of the word within this batch. This identification number accompanies all forms of a word throughout compilation, to facilitate the identification of Russian words represented in the ranked code, and the tracing of errors. Of the last three digits of the fifth machine word, the two low order ones specify the character position within a machine word at which the last letter of the Russian word occurs, while the high order digit specifies the machine word (0, 1, or 2) in which the last letter of the Russian word occurs. These numbers are computed during the initial code conversion, and are used to control shifting and extracting operations when the Russian word undergoes later transformations.

After the lists of Figs. 6 and 7 have been checked for errors, the Russian word tapes are ready for automatic inflection (9). This process is illustrated in Fig. 8, with the verb писать as an example. This verb is shown with its inflectional class marker V5, assigned as described in Section 3. The forms generated after one inflection run are indicated in column α of Fig. 8. It will be noted that adjectival inflectional class markers are given next to the participial standard canonical forms. These forms are generated by the inflector routine, together with their class markers. Therefore, the inflection of the participles is entirely automatic, without need for further manual classification.

The inverse inflection algorithm is then automatically applied to the set of distinct inflected forms, splitting each into an ending and a potential stem canonical form. The resulting set of stems is condensed to yield a list where only one representative of each distinct type of stem is retained. As in the example of Fig. 1, and for the same reasons, some artificial forms are generated which do not properly belong to the paradigm of the verb писать. These forms are marked on the diagram by the letter I. In addition, several so-called academic forms are generated. These are distinguished from the artificial forms in that they are morphologically acceptable members of the paradigm of писать but are very unlikely to occur in actual texts. Stems obtained from artificial or academic forms can be identified and deleted, if desired, at the time that English correspondents are assigned. In case of doubt they are retained, to be deleted when their zero frequency of use after a long period **of** operation automatically indicates that they should be.

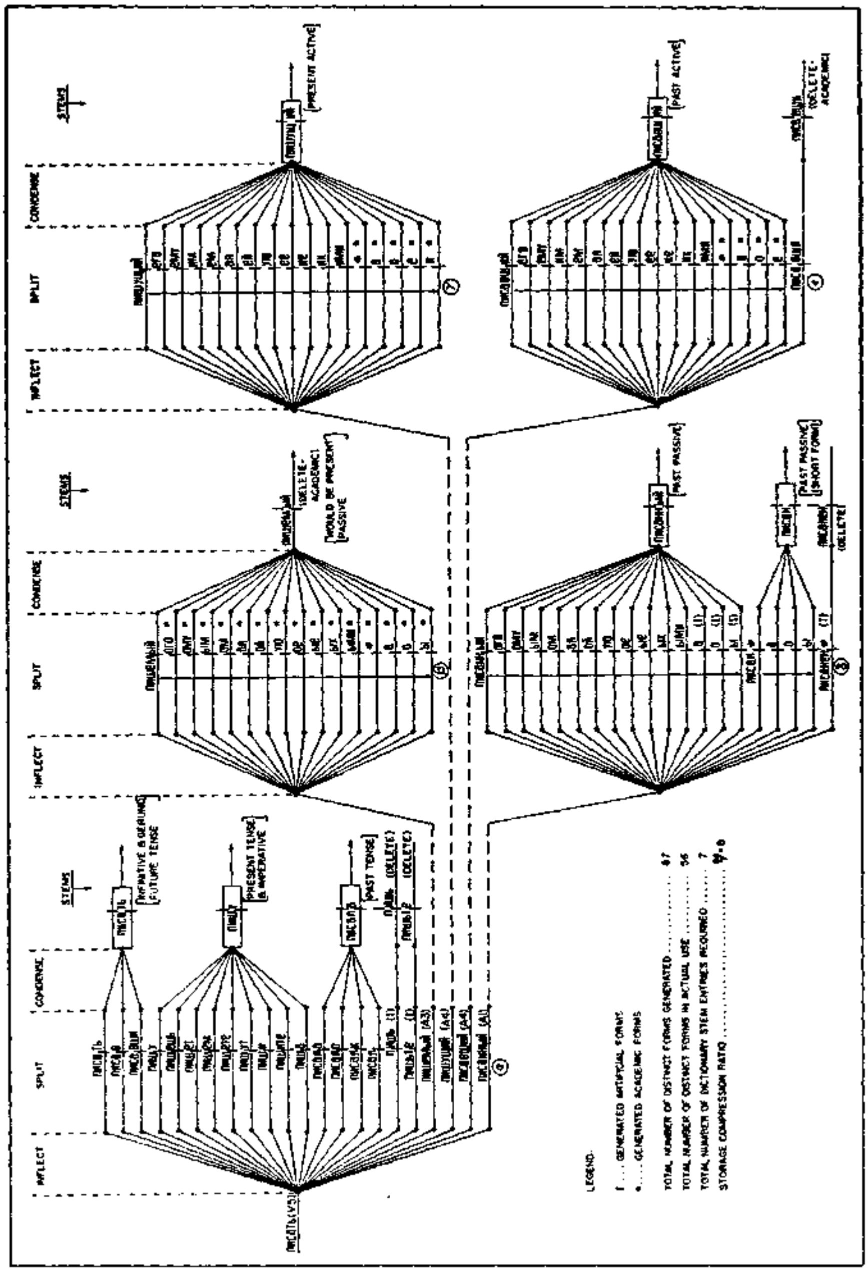
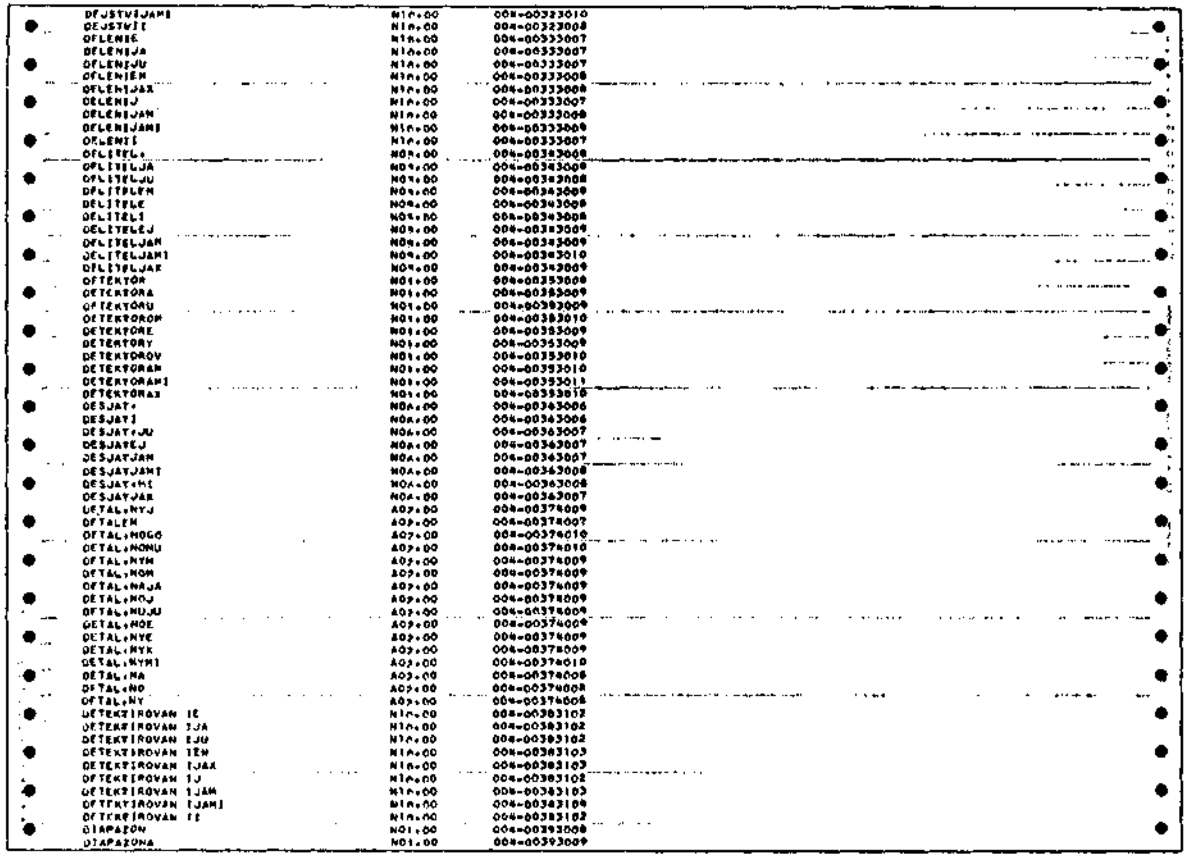

INFLECT
SPLIT
CONDENSE
STEMS
писать(V5)
писа|ть
[INFINITIVE & GERUND FUTURE TENSE]
пиш|у
[PRESENT TENSE & IMPERATIVE]
писал
[PAST TENSE]
пишь (DELETE)
пишьте (DELETE)
пишемый (A3)
пишущий (A4)
писавший (A4)
писанный (A1)
пишемый
(DELETE-ACADEMIC)
[WOULD BE PRESENT PASSIVE]
пишущ|ий
[PRESENT ACTIVE]
писанн|ый
[PAST PASSIVE]
писан
[PAST PASSIVE (SHORT FORM)]
(DELETE)
писавш|ий
[PAST ACTIVE]
писавши
(DELETE-ACADEMIC)
LEGEND.
! ... GENERATED ARTIFICIAL FORMS
• .... GENERATED ACADEMIC FORMS
TOTAL NUMBER OF DISTINCT FORMS GENERATED 47
TOTAL NUMBER OF DISTINCT FORMS IN ACTUAL USE 56
TOTAL NUMBER OF DICTIONARY STEM ENTRIES REQUIRED 7
STORAGE COMPRESSION RATIO .... 56/7=8

FIGURE 8. The generation of paradigms and canonical stems.

In practice, automatic inflection is separated into three major runs. Words marked with nominal and verbal class markers are inflected before those with adjectival class markers. This means that, on the last run, those adjectival forms generated together with their class markers as a result of verb inflection can be inflected with the other adjectives. A list of inflected forms obtained from the jnflector runs is shown in Fig. 9. A similar list, showing forms after splitting of their endings, is given in Fig. 10. Adjectival forms generated as a result of verb inflection are distinguished by the presence of one of the letters A, B, C,



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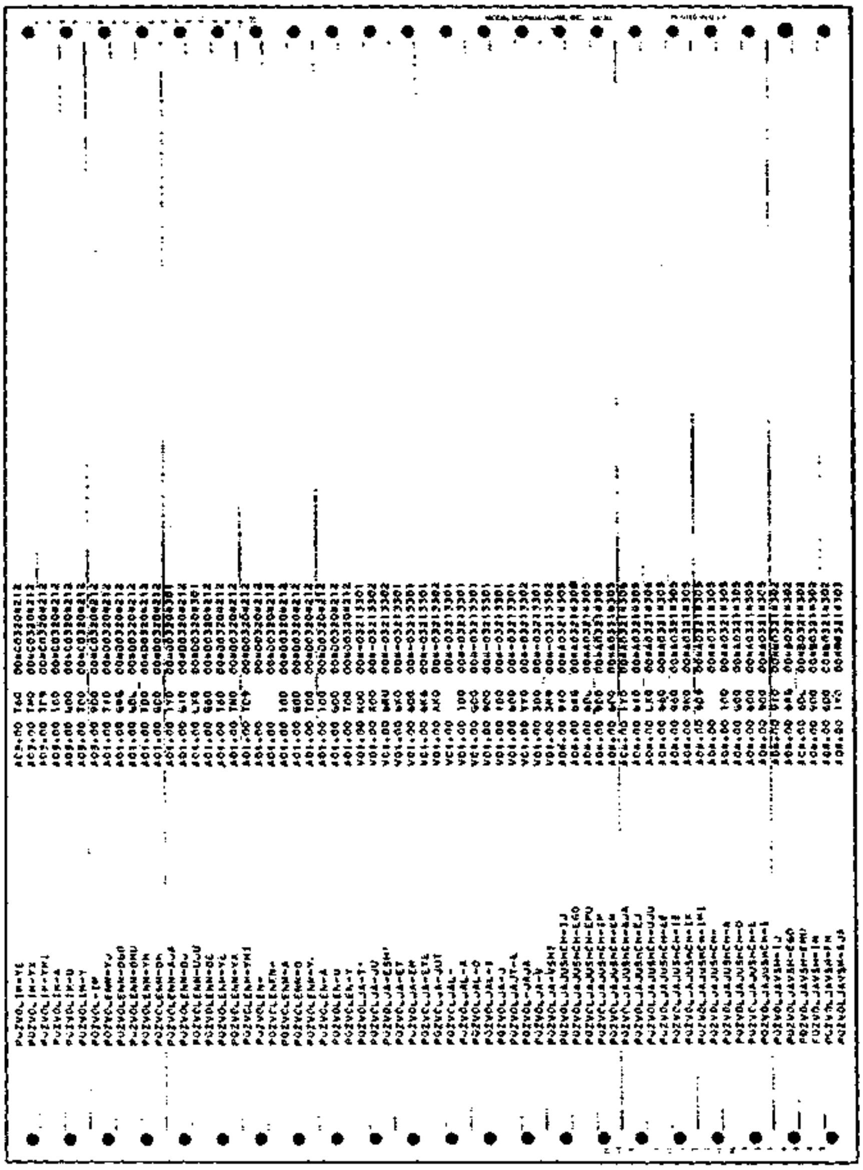
DEJSTVII                 N1A.00   004-00323008
DELENIE                  N1A.00   004-00333007
DELENIJA                 N1A.00   004-00333007
DELENIJU                 N1A.00   004-00333007
DELENIEM                 N1A.00   004-00333008
DELENIJAX                N1A.00   004-00333008
DELENIJ                  N1A.00   004-00333007
DELENIJAM                N1A.00   004-00333008
DELENIJAMI               N1A.00   004-00333009
DELENII                  N1A.00   004-00333007
DELITEL+                 N09.00   004-00343008
DELITELJA                N09.00   004-00343008
DELITELJU                N09.00   004-00343008
DELITELEM                N09.00   004-00343009
DELITELE                 N09.00   004-00343008
DELITELI                 N09.00   004-00343008
DELITELEJ                N09.00   004-00343009
DELITELJAM               N09.00   004-00343009
DELITELJAMI              N09.00   004-00343010
DELITELJAX               N09.00   004-00343009
DETEKTOR                 N01.00   004-00353008
DETEKTORA                N01.00   004-00353009
DETEKTORU                N01.00   004-00353009
DETEKTOROM               N01.00   004-00353010
DETEKTORE                N01.00   004-00353009
DETEKTORY                N01.00   004-00353009
DETEKTOROV               N01.00   004-00353010
DETEKTORAM               N01.00   004-00353010
DETEKTORAMI              N01.00   004-00353011
DETEKTORAX               N01.00   004-00353010
DESJAT+                  N0A.00   004-00363006
DESJATI                  N0A.00   004-00363006
DESJAT+JU                N0A.00   004-00363007
DESJATEJ                 N0A.00   004-00363007
DESJATJAM                N0A.00   004-00363007
DESJATJAMI               N0A.00   004-00363008
DESJAT+MI                N0A.00   004-00363008
DESJATJAX                N0A.00   004-00363007
DETAL+NYJ                A07.00   004-00374009
DETALEN                  A07.00   004-00374007
DETAL+NOGO               A07.00   004-00374010
DETAL+NOMU               A07.00   004-00374010
DETAL+NYM                A07.00   004-00374009
DETAL+NOM                A07.00   004-00374009
DETAL+NAJA               A07.00   004-00374009
DETAL+NOJ                A07.00   004-00374009
DETAL+NUJU               A07.00   004-00374009
DETAL+NOE                A07.00   004-00374009
DETAL+NYE                A07.00   004-00374009
DETAL+NYX                A07.00   004-00374009
DETAL+NYMI               A07.00   004-00374010
DETAL+NA                 A07.00   004-00374008
DETAL+NO                 A07.00   004-00374008
DETAL+NY                 A07.00   004-00374008
DETEKTIROVAN IE          N1A.00   004-00383102
DETEKTIROVAN IJA         N1A.00   004-00383102
DETEKTIROVAN IJU         N1A.00   004-00383102
DETEKTIROVAN IEM         N1A.00   004-00383103
DETEKTIROVAN IJAX        N1A.00   004-00383103
DETEKTIROVAN IJ          N1A.00   004-00383102
DETEKTIROVAN IJAM        N1A.00   004-00383103
DETEKTIROVAN IJAMI       N1A.00   004-00383104
DETEKTIROVAN II          N1A.00   004-00383102
DIAPAZON                 N01.00   004-00393008
DIAPAZONA                N01.00   004-00393009
```

FIGURE 9. Inflected forms.



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POZVOLIM-YX             A03.00 TMO   00*C03204212
POZVOLIM-YMI            A03.00 3T9   00*C03204212
POZVOLIM-A              A03.00 100   00*C03204212
POZVOLIM-U              A03.00 400   00*C03204212
POZVOLIM-Y              A03.00 T00   00*C03204212
POZVOL-IM               A03.00 900   00*C03204212
POZVOLENN-YJ            A01.00 T10   00*D03204212
POZVOLENN-OGO           A01.00 6*6   00*D03204212
POZVOLENN-OMU           A01.00 40L   00*D03204212
POZVOLENN-YM            A01.00 T00   00*D03204212
POZVOLENN-OM            A01.00 900   00*D03204212
POZVOLENN-AJA           A01.00 1Y0   00*D03204301
POZVOLENN-OJ            A01.00 610   00*D03204212
POZVOLENN-UJU           A01.00 LY0   00*D03204301
POZVOLENN-OE            A01.00 960   00*D03204212
POZVOLENN-YE            A01.00 160   00*D03204212
POZVOLENN-YX            A01.00 TNO   00*D03204212
POZVOLENN-YMI           A01.00 TC9   00*D03204212
POZVOLEN-               A01.00       00*D03204212
POZVOLENEN-             A01.00       00*D03204212
POZVOLENN-A             A01.00 100   00*D03204212
POZVOLENN-O             A01.00 600   00*D03204212
POZVOLENN-Y.            A01.00 T00   00*D03204212
POZVOLEN-A              A01.00 100   00*D03204212
POZVOLEN-U              A01.00 600   00*D03204212
POZVOLEN-Y              A01.00 T00   00*D03204212
POZVOLJA-T'             V01.00 KO0   00*-03213301
POZVOLJA-JU             V01.00 X00   00*-03213302
POZVOLJA-ESH'           V01.00 MRU   00*-03213302
POZVOLJA-ET             V01.00 MKO   00*-03213301
POZVOLJA-EM             V01.00 400   00*-03213301
POZVOLJA-ETE            V01.00 4K6   00*-03213301
POZVOLJA-JUT            V01.00 AKO   00*-03213302
POZVOLJAL-              V01.00       00*-03213301
POZVOLJAL-A             V01.00 100   00*-03213301
POZVOLJAL-O             V01.00 600   00*-03213301
POZVOLJAL-I             V01.00 900   00*-03213301
POZVOLJA-J              V01.00 100   00*-03213301
POZVOLJAJT-E            V01.00 600   00*-03213301
POZVOL-JAJA             V01.00 YY0   00*-03213302
POZVOLJA-V              V01.00 300   00*-03213301
POZVOLJA-VSHI           V01.00 3M9   00*-03213302
POZVOLJAJUSHCH-IJ       A04.00 910   00*A03214305
POZVOLJAJUSHCH-EGO      A04.00 6*6   00*A03214308
POZVOLJAJUSHCH-EMU      A04.00 40L   00*A03214305
POZVOLJAJUSHCH-IM       A04.00 T00   00*A03214305
POZVOLJAJUSHCH-EM       A04.00 900   00*A03214305
POZVOLJAJUSHCH-AJA      A04.00 1Y0   00*A03214306
POZVOLJAJUSHCH-EJ       A04.00 610   00*A03214305
POZVOLJAJUSHCH-UJU      A04.00 LY0   00*A03214306
POZVOLJAJUSHCH-EE       A04.00 960   00*A03214305
POZVOLJAJUSHCH-IE       A04.00 460   00*A03214305
POZVOLJAJUSHCH-IX       A04.00 9K0   00*A03214305
POZVOLJAJUSHCH-IMI      A04.00 TC9   00*A03214305
POZVOLJAJUSHCH-         A04.00       00*A03214305
POZVOLJAJUSHCH-A        A04.00 100   00*A03214305
POZVOLJAJUSHCH-O        A04.00 600   00*A03214305
POZVOLJAJUSHCH-E        A04.00 400   00*A03214305
POZVOLJAJUSHCH-I        A04.00 900   00*A03214305
POZVOLJAVSH-IJ          A04.00 910   00*B03214302
POZVOLJAVSH-EGO         A04.00 6*6   00*B03214302
POZVOLJAVSH-EMU         A04.00 40L   00*B03214302
POZVOLJAVSH-IM          A04.00 T00   00*B03214302
POZVOLJAVSH-EM          A04.00 900   00*B03214302
POZVOLJAVSH-AJA         A04.00 1Y0   00*B03214303
```

FIGURE 10. Split inflected forms.

or D in their serial number, in the position where a hyphen occurs in all other words. On the magnetic tapes used for further processing, only a stem is present in the first three machine words. The split ending is stored in the last five character positions of the fourth machine word of the item, where it may be seen in ranked code. Of these five characters, three are reserved for normal endings, the last two are spaces except for verbs ending in -ся or -сь. For ease in reading transliterated lists of split forms, the endings stored in these positions are brought back into the first three machine words during the transliteration run. The hyphen is inserted to mark the position of the split.

The list of distinct stems obtained by automatically condensing a list of the type illustrated in Fig. 10 is printed with the layout shown in Fig. 11. This layout is designed to guide the manual inscription of English correspondents and of grammatical coding associated with the stem canonical forms. The paper is ruled to show clearly the divisions between machine words; exactly

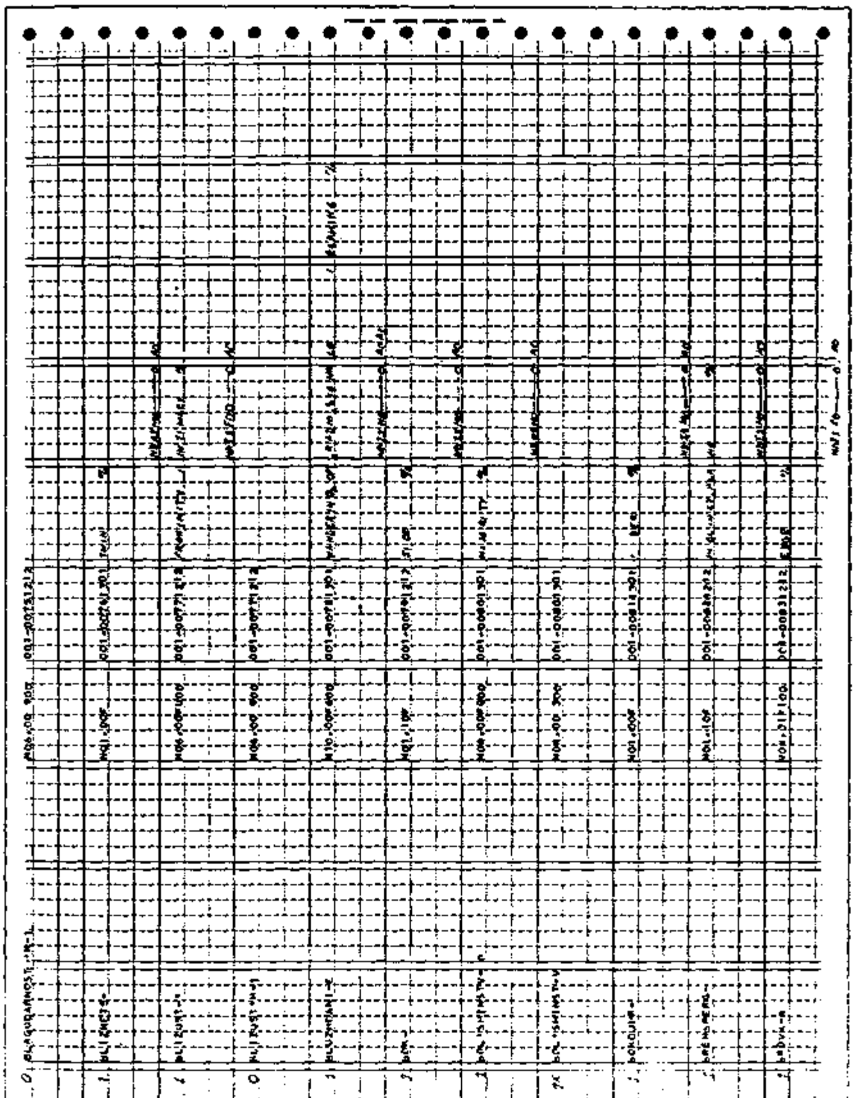


FIGURE 11. Dictionary work sheet.

two characters must be written in the spaces defined by the vertical dashed lines. Heavy black horizontal lines delimit the space allowed for an entry. Dictionary entries are items consisting of thirty machine words, of which the first five make up a standard Russian item. The last twenty-five machine words are devoted to correspondents and to grammatical information. The English correspondents are written immediately after the Russian item. The - last four of the twenty-five words are reserved for coded information. Distinct correspondents are numbered, the last correspondent being marked by the use of a percent sign in place of a numeral.

An effort is made to rank the correspondents in the order of their likely frequency of use. Initially, this ranking is necessarily somewhat arbitrary. It is expected that, as a major by-product of automatic dictionary operation, the sets of correspondents and their ordering will gradually be adjusted in accordance with the experience of the technical experts who are the ultimate users of translations and the best judges of their value.

In the first of the four words reserved for coded information, the significance of a character depends on its position within the word. This word is therefore called the "organized word." In the other three words, the significance of characters is independent of their position within the set of three words. These words are therefore called "semiorganized words." Because the inflectional class markers have chiefly formal significance, one of the major functions of the coded information in the organized word is to identify the functional role of the entry. This may be illustrated by the following two examples: a word declined like an adjective may function as a noun and will be coded as such in the organized word; the set of words classified as formally indeclinable includes, along with prepositions and conjunctions, some words functioning as nouns, and these are distinguished by an appropriate notation. Functionally distinct paradigms lumped into one inflectional class to simplify classification and automatic inflection are also distinguished by means of a notation in the organized word. For example, the distinction between animate and inanimate nouns is of no consequence so far as the generation of distinct inflected forms is concerned, but it is vital to the interpretation of the functional significance of endings. That distinction is therefore made by means of a symbol in the organized word. Such information as the names of dictionaries or texts consulted in preparing the entry is mentioned in the semiorganized word. In addition, important grammatical data, whose range of application is insufficient to justify their inclusion in the organized word, are introduced in the semiorganized words.

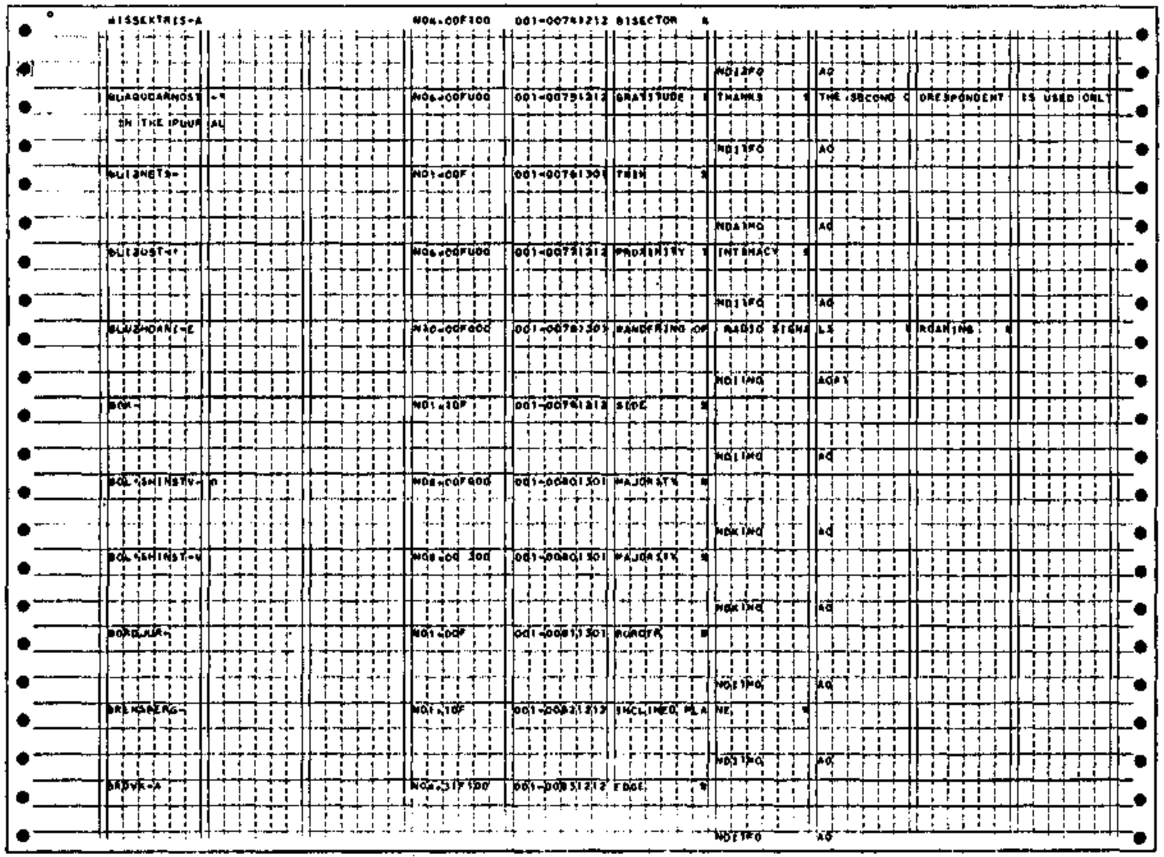
Although every effort is made to provide for coded information of wide scope, it is clearly not possible to foresee all contingencies likely to be met in experimental work. Therefore, the space between the percent sign marking the end of the last English correspondent and the organized word is left free for the insertion of ad lib English prose comments. In this way, information of significance whose need was not foreseen in planning the layout of the organized and semiorganized words, or likely to apply to too few entries to warrant inclusion in these words, may be recorded and retrieved automatically at a later date. The systematic inclusion of such information into the organized words is possible whenever large enough classes of similar comments are found.

After the correspondents and coded information have been written as shown in Fig. 11, the handwritten material is transcribed onto a magnetic tape. This tape is then merged with that containing the Russian stems, and the complete dictionary entries are recorded on a new tape. The markings in the left-hand margin of Fig. 11 are used to control in part the process of dictionary assembly. A zero in the left-hand margin indicates that the stem is to be deleted and not to appear in the final dictionary. This is the means for deleting spurious or academic forms, or errors detected earlier but not then corrected.

The paradigms of nouns and adjectives where vowel insertion occurs, and of many verbs, may be represented in the list of Fig. 11 by more than one stem. This problem of multiple stems has been discussed in detail elsewhere (6). Whenever two or more stems belong to the same paradigm, they are identified by the same serial number. The first stem in such a set is always that split from the standard dictionary canonical form, and is marked by the letter F in the seventh column of the fourth machine word of the Russian item. Unless it is to be deleted, this stem is usually given a left-hand margin marker 1. If other stems with the same serial number require precisely the same English correspondents and coded information, repeated writing of this information is not necessary. It is sufficient to write the symbol 1R in the left-hand margin for such entries. Where one or more of a set of stems with the same serial number require a set of correspondents distinct from that assigned to the F form, the margin markers 2, 2R, 3, 3R, etc., may be used.

In transcribing the English and coded material, each entry is identified simply by its left-hand margin marker and the serial number. The whole Russian entry need not be copied.

Once the correspondents have been transcribed onto magnetic tapes, they are automatically assembled with their stems. A section of assembled dictionary is shown in Fig. 12. It should be pointed out again in this connection that Russian word forms in dictionary entries are stored in the ranked code on magnetic tape and are represented by stems only. Endings are introduced during the process of transliteration only to facilitate human recognition of the printed entries.



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BISSEKTRIS-A                    NO4.00F100   001-00741212 BISECTOR     A
                                                               NO12FO         AO
BLAGODARNOST  -Y                NO6.00FU00   001-00751212 GRATITUDE    T THANKS       T THE SECOND C ORRESPONDENT  IS USED ONLY
  IN THE PLURAL
                                                               NO11FO         AO
BLIZNETS-                       NO1.00F      001-00761301 TWIN         S
                                                               NDA1NG         AO
BLIZOST-Y                       NO6.00FU00   001-00771212 PROXIMITY    T INTIMACY     S
                                                               NO11FO         AO
BLUZHDANI-E                     NAO.00F000   001-00781301 WANDERING OF  RADIO SIGNA LS             S ROAMING     S
                                                               NO11NG         AGPY
BOK-                            NO1.10F      001-00791212 SIDE         S
                                                               NO11NG         AO
BOL'SHINSTV-  O                 NO8.00F000   001-00801301 MAJORITY     S
                                                               NOK1NG         AO
BOL'SHINST-V                    NO8.00 300   001-00801301 MAJORITY     S
                                                               NOK1NG         AO
BORDJUR-                        NO1.00F      001-00811301 BORDER       S
                                                               NO11NG         AO
BREMSBERG-                      NO1.10F      001-00821212 INCLINED PLA NE,          S
                                                               NO11NG         AO
BROVK-A                         NO4.317100   001-00831212 EDGE         S
                                                               NO11FO         AO
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FIGURE 12. Assembled dictionary.

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