Characteristics Calculation on Three Phase Induction Motor by Any Frequency Test

Characteristic Calculation on Three Phase Induction Motor by Any Frequency Test

Tsutomu TOKUDA* and Tomoo FUJII*

(Received November 30, 1962)

In this paper, discribed a method how to convert the result of no load test and short circuit test on the three phase induction motor on any frequency source into on the rated frequency ones. The merits of this method is that it requires neither three phase a-c generator nor three phase frequency converter, and that the convertion is comparatively simple. It will be particularly convenient as in Japan where has both 50 (cps) and 60 (cps) distributed regions.

1. Preface

It often occurs, where, the three phase rated frequency source is not available, how to obtain the characteristics of the three phase induction motor on the rated frequency source by any frequency test.

Generally, the characteristics of the three phase induction motor are calculated by circle diagram method, in which the following tests are indispensable: (1) No load test, (2) Lock test, and (3) Measurment of the resistance between two terminals of the stator.

(1). The input current obtained by no load test may be decomposed into active and reactive components. Of these components the active current is the current to compensate copper loss, iron loss and mechanical loss, and the reactive one is the magnetizing current or exciting current.

One of the purposes in this paper is to lead the converting equation by means of the relations between these current and frequency.

(2). The input current obtained by the lock test may be decomposed as follows; active current: the current to compensate copper loss depending on the equivalent short circuit resistance, and reactive current: the current to supply reactive power depending on the equivalent short circuit reactance. The equivalent short circuit resistance is constant on any frequency and the equivalent short circuit reactance is proportional to the frequency. Consequently, the equivalent short circuit reactance and impedance on the rated frequency may be easily calculated.

Another purpose in this paper is to calculate the lock test values on the rated frequency by means of converted impedance.

(3). The resistance between terminals of the stator is constant on any frequency.

2. Conversion of No Load Test Values

The rating of the testing three phase induction motor is, frequency f_1, voltage E_1 and the frequency of the testing source is f_2, respectively. When a three phase induction

* Department of Electrical Engineering, College of Engineering.

motor is running on the rated voltage E_1 and frequency f_1, the flux Φ is represented as follows,

$$\Phi = K \times E_1/f_1 \tag{1}$$

where $K = 1/(\sqrt{3} \times 4.44 \times K_w N)$

$K_w N$=effective primary no. of turns per phase.

Consequently, even if the available frequency f_2 is differ from rated frequency f_1, as long as the supply voltage E_2 is adjusted so that it may satisfy the following relationship,

$$E_2 = E_1 \times f_2/f_1 \tag{2}$$

the flux will be kept at the same value Φ in Eq. (1).

When the no load test results on the voltage E_1, frequency f_1, and on the voltage E_2, frequency f_2, are obtained as follows,

$$\left.\begin{array}{lll} \text{supply voltage} & E_1, & E_2 \\ \text{frequency} & f_1, & f_2 \\ \text{no load current} & I_{01}, & I_{02} \\ \text{no load loss} & W_{01}, & W_{02} \end{array}\right\} \tag{3}$$

the no load currnt may have the components as shown in Eq. (4), respectively,

$$\left.\begin{array}{ll} \text{active component of } I_{01}: & i_{01} = W_{01}/(\sqrt{3} \times E_1) \\ \text{reactive component of } I_{01}: & i_{02} = \sqrt{I_{01}^2 - i_{01}^2} \\ \text{active component of } I_{02}: & a_{01} = W_{02}/(\sqrt{3} \times E_2) \\ \text{reactive component of } I_{02}: & a_{02} = \sqrt{I_{02}^2 - i_{02}^2} \end{array}\right\} \tag{4}$$

2.1. Conversion of Reactive Compoent of No Load Current

Since the voltage and frequency have the relation, $E_1/f_1 = E_2/f_2$, as shown in Eq. (2), and the flux of both tests are identical, so the reactive component of no load current are identical, namely,

$$i_{02} = a_{02} \tag{5}$$

hence, the conversion is not necessary for the reactive component.

2.2. Conversion of Active Component of No Load Current

The active component of no load current which provide with iron loss, mechanical loss and no load copper loss, is so small compared with the reactive component that it may be neglected sometimes. The follwing example shows how much the errors of no load current have an influence on the characteristics of the motor. The rating of the testing motor is as follows, output=2.2 (KW), voltage=200 (V), no. of poles=4, frequency=50 (cps) respectively. Table 1 shows the experimental results of no. load and short circuit test of this motor, and Table 2 shows the errors in full load characteristic calculation, which are caused by assuming that the active component of no load current is 150 %, 120 %, 100 %, 80 %, 50 %, 0 % aganist the measured value. As shown in Table 2, only 6.87 % decrease is resulted in the full load current because the active component of no load current is assumed to be $i_{01}=0$. Further, as long as the error of i_{01} is kept within 20 %, the errors

Table 1. Results of the tests.

No load test		
rated voltage	$E_1=200$	(V)
rated frequency	$f_1=50$	(cps)
no load current	$I_0=3.98$	(A)
no load loss	$W_0=257$	(W)
active component of no load current	$i_{01}=0.743$	(A)
reactive component of no load current	$i_{02}=3.91$	(A)
Short circuit test		
short circuit voltage	$E_s=41.3$	(V)
frequency	$f_1=50$	(cps)
short circuit current	$I_s'=8$	(A)
short circuit loss	$W_s=438$	(W)
short circuit current at rated voltage	$I_s=38.74$	(A)
active component of I_s	$i_{s1}=29.65$	(A)
reactive component of I_s	$i_{s2}=24.93$	(A)
Resistance between stator terminals		
resistance between stator terminals	$R=1.6$	(Ω)
ambient temperature	$t=28$	(°C)

Table 2. Errors in full load characteristics.

ratio of active component of no load current against the measured value (%)	150	120	100	80	50	0
active component of no load current i_{01} (A)	1.115	0.892	0.743	0.594	0.372	0
in put current I_1 (A)	10.08	9.93	9.78	9.66	9.46	9.11
errors in input current (%)	+3.06	+1.52	0	−1.25	−3.27	−6.87
power factor $\cos\varphi$ (%)	87.73	86.88	86.61	86.15	85.58	84.60
erros in power factor (%)	+1.29	+0.31	0	−0.53	−1.19	−2.32
efficiency η (%)	71.77	73.64	75.0	76.35	78.46	82.43
errors in efficiency (%)	−4.31	−1.81	0	+1.80	+4.61	+9.91
slip s (%)	6.13	6.12	6.08	6.07	6.05	5.97
errors in slip (%)	+0.83	+0.66	0	−0.16	−0.49	−1.81
max. out put P_{max} (%)	154.5	155.1	155.6	156.0	156.5	157.6
errors in max. out put (%)	−0.71	−0.32	0	+0.26	+0.64	+1.29
stalling torque T_{max} (%)	293.7	295.5	297.0	297.9	299.6	302.3
errors in stalling torque (%)	−1.11	−0.50	0	+0.30	+0.88	+1.78

of the full load characteristics are limited within 2%. Therefore, in constructing the circle diagram, the active component of no load current proved to be not so essential element.

The results of no load tests on the testing motor on the voltage $E_1=200$ (V), the frequency $f_1=50$ (cps): the rating of the motor, and $E_2=240$ (V), $f_2=60$ (cps): choosed value so as to satisfy the ratio $E_1/f_1=E_2/f_2$, are given in Table 3, in which the reactive components of no load current of both cases nearly identical with each other and the active componepts have but a negligible diviation of 0.54%. Consequently, the values obtaind on voltage E_2, frequency f_2 can be regarded as the substitute of the values at rated voltage E_2 and frequency f_1. It may be given,

$$i_{01}=a_{01} \tag{6}$$

Table 3. Results of no load tests.

frequency (cps)	$f_1=50$	$f_2=60$
voltage (V)	$E_1=200$	$E_2=240$
no load current (A)	$I_{01}=3.98$	$I_{02}=4.0$
no load loss	$W_{01}=257$	$W_{02}=307$
active component of no load current (A)	$i_{01}=0.743$	$a_{01}=0.739$
reactive component of no load current (A)	$i_{02}=3.91$	$a_{02}=3.90$

For further reference, no load characteristics of the testing motor for the frequency $f=50$ (cps) and 60 (cps) are plotted aganist E/f in Figs. 1~4 and E^2/f in Figs. 5~8.

3. Conversion of Short Circuit Test Values

The results of short circuit test on any frequency f_2 are represented by

$$\left.\begin{array}{ll} \text{short circuit current (approximately full load current)} & =I_{s2}\ \text{(A)} \\ \text{impedance voltage} & =E_{s2}\ \text{(V)} \\ \text{frequency} & =f_2\ \text{(cps)} \\ \text{input (on the short circuit test)} & =W_{s2}\ \text{(W)} \end{array}\right\} \tag{7}$$

it follows that

$$\left.\begin{array}{ll} \text{equivalent resistance} & R_2=W_{s2}/(3\times I_{s2}^2) \\ \text{equiqalent impedance} & Z_2=E_{s2}/(\sqrt{3}\times I_{s2}) \\ \text{equivalent reactance} & X_2=\sqrt{Z_2^2-R_2^2} \end{array}\right\} \tag{8}$$

The frequency has no effect on the equivalent resistance in the case of ordinal squirrel cage type and wound rotor type motors, but on the equivalent short circuit reactance propotionally. Therefore, the equivalent short circuit reactance X_1 on the rated frequency f_1 may be represented as follows,

$$X_1=X_2\times f_1/f_2 \tag{9}$$

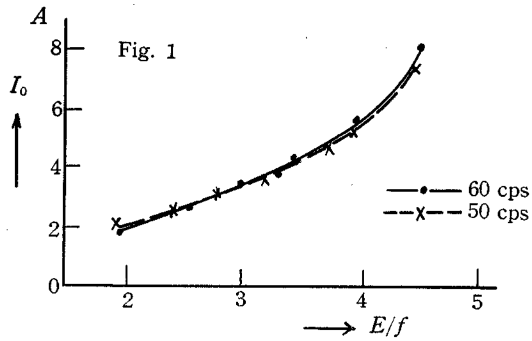

Fig. 1

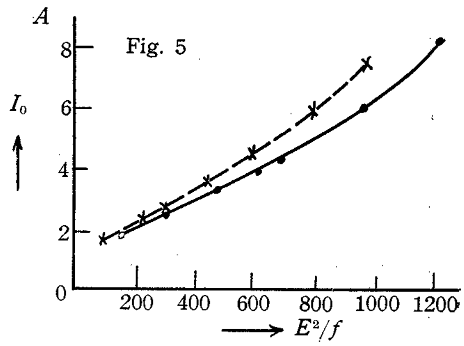

Fig. 5

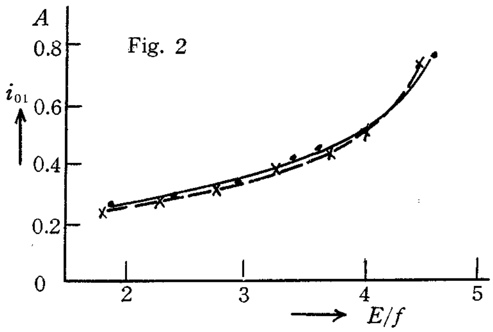

Fig. 2

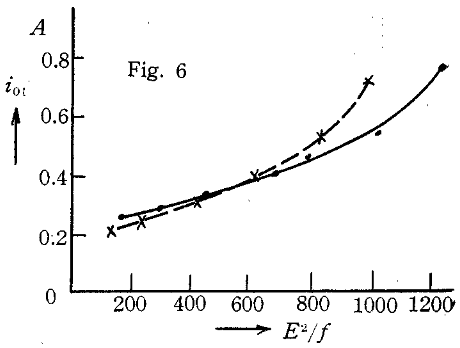

Fig. 6

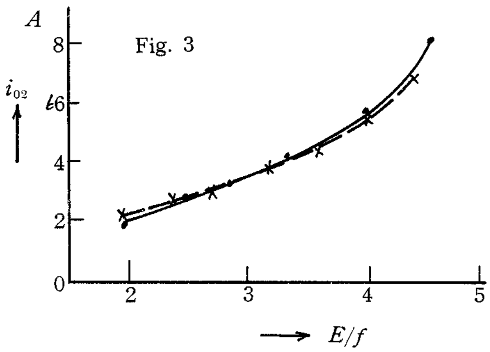

Fig. 3

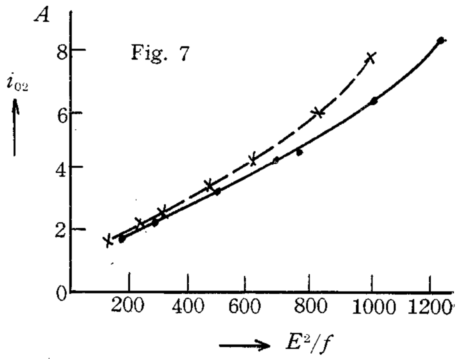

Fig. 7

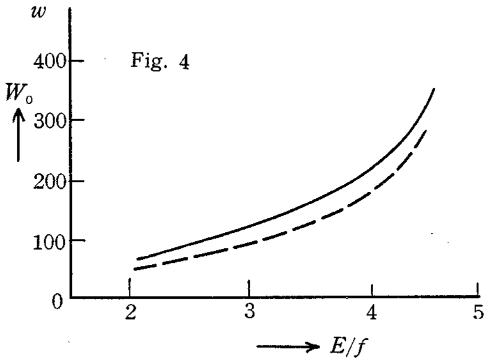

Fig. 4

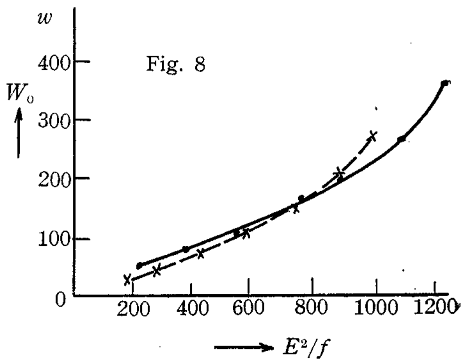

Fig. 8

Table 4. Experimental results

Rating		capacity	KW	3.7	3.7	3.7	2.2	2.2	2.2	1.5	1.5	1.5
		frequency	cps	50	60	60	50	60	60	50	60	60
		voltage	V	200	200	220	200	200	220	200	200	220
		no of pole		4	4	4	4	4	4	4	4	4
		rotor		cage	cage	cage	cage	cage	cage	cage	cage	cage
results on the rated frequency	no load test	frequency	f_1	50	60	60	50	60	60	50	60	60
		voltage	E_1	200	200	220	200	200	220	200	200	220
		current	I_{01}	5.83	4.1	4.86	3.98	2.98	3.45	3.0	2.3	2.62
		input	W_{01}	196	146	182	257	239	272	215	214	236
		active comp.	i_{01}	0.567	0.422	0.479	0.743	0.691	0.715	0.622	0.619	0.621
		reactive comp.	i_{02}	5.80	4.08	4.84	3.915	2.89	3.37	2.92	2.215	2.55
	short circuit test	frequency	f_1	50	60	60	50	60	60	50	60	60
		current	I_S	13	13	13	8	8	8	6	6	6
		voltage	E_{S1}	42.1	48.7	48.7	41.3	44.2	44.2	50	53.4	53.4
		input	W_{S1}	504	504	504	438	435	435	430	439	439
the any frequency	no load test	frequency	f_2	60	50	50	60	50	50	60	50	50
		voltage	E_2	240	166.5	183	240	166.5	183	240	166.5	183
		current	I_{02}	5.79	4.1	4.87	4.0	2.98	3.4	3.08	2.28	2.58
		input	W_{02}	236	120	146	307	195	220	268	169	189
		active comp.	a_{01}	0.568	0.417	0.461	0.739	0.677	0.695	0.646	0.587	0.597
		reactive comp	a_{02}	5.75	4.07	4.86	3.94	2.91	3.33	3.01	2.205	2.54

results on	short ciecuit test	frequency f_2	60		50		50		60		50		50		60		50		50	
		current I_{s2}	13		13		13		8		8		8		6		6		6	
		voltage E_{r2}	48.6		42.1		42.1		44.2		41.3		41.3		53.4		50		50	
		input W_{s2}	504		504		504		435		438		438		439		430		430	
		equivalent resist. R_2	0.994		0.994		0.994		2.265		2.28		2.28		4.065		3.98		3.98	
		〃 reactance X_2	1.915		1.58		1.58		2.25		1.925		1.925		3.195		2.72		2.72	
		〃 impedance Z_2	2.163		1.872		1.872		3.194		2.985		2.985		5.15		4.82		4.82	
			A*	B*	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	mean error (%)
comparison		equivalent resist. R_1	0.994	0.994	0.994	0.994	0.994	0.994	2.28	2.265	2.265	2.28	2.265	2.28	3.98	4.065	4.065	3.98	4.065	3.98	1.22
		〃 reactance X_1	1.58	1.595	1.915	1.898	1.915	1.898	1.925	1.875	2.25	2.31	2.25	2.31	2.72	2.66	3.175	3.26	3.175	3.26	1.70
		〃 impedance Z_1	1.872	1.88	2.163	2.14	2.163	2.14	2.985	2.94	3.195	3.255	3.195	3.255	4.82	4.84	5.16	5.15	5.16	5.15	0.82
		short eircuit vtg. E_{s1}	42.1	42.4	48.7	48.2	48.7	48.2	41.3	40.7	44.2	45	44.2	45	50	50.2	53.4	53.4	53.4	53.4	0.81
circle diagram elements		no load current I_{01}	5.83	5.79	4.1	4.1	4.86	4.87	3.98	4.0	2.98	2.98	3.45	3.4	3	3.08	2.3	2.28	2.62	2.58	0.92
		〃 active comp. i_{01}	0.567	0.568	0.422	0.417	0.479	0.461	0.743	0.739	0.691	0.677	0.715	0.695	0.622	0.646	0.619	0.587	0.621	0.597	2.94
		〃 reactive comp. i_{02}	5.80	5.75	4.08	4.07	4.84	4.86	3.915	3.94	2.89	2.91	3.37	3.33	2.92	3.01	2.215	2.205	2.55	2.54	1.06
		short circuit ct. I_s	61.8	61.9	53.4	53.9	58.7	59.3	38.75	39.3	36.2	35.55	39.8	39.1	24	23.9	22.4	22.4	24.6	24.6	0.71
		〃 active comp. i_{s1}	32.78	32.75	24.7	24.81	26.96	27.58	29.6	30.4	25.65	24.95	28.2	27.45	19.8	20.00	17.7	17.65	19.30	18.95	1.24
		〃 reactive comp. i_{s2}	52.1	52.5	47.6	47.4	51.9	52.7	25.0	25.1	25.5	25.35	28.0	27.9	13.53	13.15	13.8	14.2	15.18	15.60	1.49

*A Values obtained on the rated frequency tests.

*B Converted values, which are obtained on any frequency tests.

so the equivalent short circuit impedance Z_1 on the rated frequency f_1 is

$$Z_1=\sqrt{R_2^2+X_1^2} \qquad (10)$$

and the short circuit impedance voltage E_{s1} on I_{s2} is given by

$$E_{s1}=\sqrt{3}\times I_{s2}\times Z_1 \qquad (11)$$

Consequently, the results of short circuit test are obtained as follows,

$$\left.\begin{array}{ll} \text{short circuit current on the rated voltage} & I_{s1}=I_{s2}\times E_1/E_{s1} \\ \text{active component of short circuit current} & i_{s1}=I_{s1}\times R_2/Z_1 \\ \text{reactive component of short circuit current} & i_{s2}=I_{s1}\times X_1/Z_1 \end{array}\right\} \qquad (12)$$

From thus calculated elemental values that are obtained in Eqs. (5), (6) and (12), the full load characteristics on the rated frequency and voltage may be calculated by means of circle diagram method or JIS method.*

4. Experimental Results

On the various ratings of three phase induction motors, the rated voltage E_1 and frequency f_1 were provided following three ways, 200 (V)~50 (cps), 200 (V)~60 (cps) and 220 (V)~60 (cps). So the voltage E_2 and frequency f_2 of testing source were chosen so as to satisfy the relation $E_1/f_1=E_2/f_2$ as follows, 240 (V)~60 (cps), 166.5 (V)~50 (cps) and 183 (V)~50 (cps). respectively.

Table 4 shows the experimental results, where the values of circle diagram elements which are obtained by converting the no load test and short circuit test values on the testing frequency f_2 to the rated frequency f_1, are compared with which are obtained under the tests on the rated voltage E_1 and frequency f_1.

5. Conclusion

The errors in the active component of no load current in question, are 0.18 % at minimum and 5.18 % at maximum under the fifteen variations of the experiments. This causes only tolerable errors and may be put to practical use. This may be said with confidence that in combination with this method and previously discribed method[1] would be very available to calculate the three phase induction motor characteristics on any frequency source.

Reference

1) This Bulletin, A 11, No. 1, 39 (1962).

* Calculating Method of Three Phase Induction Motor Characteristics: JIS-C 4207.