The Input Data of The New Member-Set of Problem 21 Family ($P21^e$)

Contents

The Input Data of The New Member-Set of Problem 21 Family ($P21^e$)

All the input data used in the modeling and simulation of the new member-set of Problem 21 ($P21^e$) have been determined, including the design parameters of the upgraded models, the electric and magnetic properties of models' materials, and the excitation current waveforms measured under specified non-sinusoidal excitation conditions.

1. Model Design Parameters and Material Electric Properties($P21^e$)

This section includes the relevant design parameters of the updated model ($P21^e$) and the electric properties of the model materials.

1.1 Design Parameters of E-coils & C-coils

The specifications of the two excitation coils and the two compensation coils used in the new member-set($P21^e$) are the same. The constructure design of the coils can be seen in Fig.1 in Section II. Table A1-1 shows further detail of the coils and copper wire.

Table A1-1
Parameters of Coil and Wire

Number of turns of coils	Dimension of square copper wire (mm)	Net sectional area of copper wire (mm^2)	Remarks
400	9.0×3.0	26.45	511.3mΩ (DC resistance of 2 coils in series)

1.2 Specifications of Magnetic and Non-magnetic Load-components

The specifications of upgraded models' load-components can be found in Table II. A brief description of models' load-components is as follows:

(a) The dimensions of the laminated sheets (B27R090, a bonded stack of 24 sheets) used in Model $P21^e$-M(NS): 1000×500×6.6(mm); The dimension of single sheet: 1000×500×0.27(mm), total 24 sheets; The assumed density of silicon steel: $7.65\times10^3 kg/m^3$.

(b) The dimensions of the copper plate(T2Y) used in Model $P21^e$-EM(NS): 1000×500×6 (mm); The assumed density of copper plate: $8.9\times10^3 kg/m^3$.

1.3 Conductivities of Magnetic and Non-magnetic Materials

1.3.1 Conductivity of Copper material

In this benchmarking, both the resistance results measured by the LCR meter (40Hz-200kHz, NF) at different frequencies, and the resistance results measured under multi-harmonic hybrid excitations using a non-inductance coils have been obtained. In the lower frequency range, different frequency and multi-harmonic excitation have little effect on the conductivity of the conducting material.

It is recommended using AC (equivalent) conductivity in modeling and simulation.

(a) Conductivity of the coil wire

The conductivities of copper wire used in both exciting coils and compensating coils are shown in Table A1-2.

Table A1-2
Conductivity of Copper Wire

Cases	Conductivity (S/m)	Remarks
AC	5.559×10^7	Copper wire(equivalent)
DC	5.850×10^7	

(b) Conductivity of copper plate

The conductivities of copper plate(T2Y) used in Model P21^{e}-EM(NS) are shown in Table A1-3.

Table A1-3
Conductivity of Copper Plate(T2Y)

Cases	Conductivity (S/m)	Remarks
AC	5.350×10^{7}	
DC	5.550×10^{7}	20°C

1.3.2 Conductivity of GO silicon steel

The conductivity of GO silicon steel(B27R090) in both rolling and transverse directions are shown in Table A1-4.

Table A1-4
GO Silicon Steel Sheets Used in P21^{e}-M(NS)

Cases	Conductivity ($\times10^{6}$ S/m)		Remarks
	Rolling direction	Transverse direction	
AC	1.874	1.869	26°C(B27R090)
DC	1.887	1.889	

2 Measured Magnetic Properties (B27R090)

The magnetic properties of GO silicon steel(B27R090， Baosteel) have been measured under different excitation conditions (Cases I-IV) using the SST(500×500 mm, Brockhaus), as shown in Fig.A2.0.

(1) The magnetic properties, including *B-H* curves and specific total loss curve(W_t-B_m), are measured in both the rolling and transverse directions.

(2) Three kinds of *B-H* curves are available, i.e., the initial magnetization curve, the DC magnetization curve, and the B_m-H_b curve. Note that H_b in the B_m-H_b curve of GO silicon steel, is the value of the magnetic field intensity H when the magnetic flux density becomes the maximum (B_m). In addition, it is recommended to use the initial magnetization *B-H* curve in Cases IV and V due to the consideration of the feasibility of the 3-D transient calculation (with DC-bias). While the B_m-H_b curves are recommended for Cases I~III.

(3) The W_t-B_m curve represents the relationship between the specific total loss W_t (including hysteresis, classical eddy current, and excess loss generated in silicon steel) and the peak value of the flux density, B_m.

(4) In Cases IV and V, the magnetic property measured under AC-DC hybrid excitation, H_{dc} represents the DC bias to be applied, which can be implemented using the enhanced magnetic measurement system (SST, Brockhaus). As a conventional value, the length of the equivalent magnetic path for 500×500 mm sample used in SST is 0.45m.

(5) In order to simplify the calculation of the iron loss inside the laminated sheets (in both the rolling and transverse directions), the average specific total loss curves are proposed based on the measured multiple specific total loss curves of different H_{dc} (B27R090) to be used in modeling and simulation.

(6) The measured DC magnetization *B-H* curves (B27R090) in both the rolling and transverse directions are also included to be used in the DC magnetic field computation.

(7) Finally, the magnetic properties of GO silicon steel (B27R090) at low frequency(5Hz) have been measured to possibly further examine the effect of very low frequency on magnetization and loss behaviors.

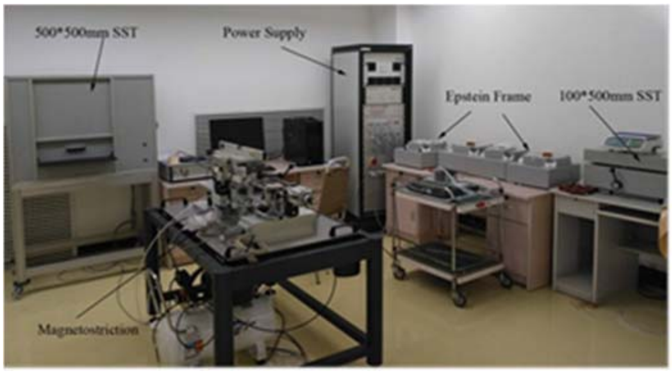


Fig. A2.0 Magnetic measuring system (Brockhaus)

Table A2.0 shows the magnetization conditions specified in magnetic measurements of GO silicon steel (B27R090) used in Model P21[e]-M(NS). Refer to Table III of the benchmarking report.

Table A2.0
Magnetic Measurements under Different Excitation Conditions

Cases	Excitation conditions	Remarks
I	$U_1 \sin(\omega t+0)$	In each case, the *B-H* curve and W_t-B_m curves were measured in rolling and transverse direction under different excitation conditions (without DC bias).
II	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$	
III	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)+U_5 \sin(5\omega t+0)+U_7 \sin(7\omega t+0)$	
IV	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$ (with DC biases)	The *B-H* curves and W_t-B_m curves were measured in rolling and transverse directions under AC and DC hybrid excitation, including 15 different DC biases.

The *B-H* curves, the W_t-B_m curves, and the corresponding sampled points data(B27R090) under different excitation conditions (Cases I~IV) are shown below.

2.1 Magnetic Properties (Case I)

2.1.1 *B-H* curves

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]
0.10000469	3.010206172	1.050139135	15.21423989
0.150015016	3.993985182	1.099929428	16.31049701
0.200016048	4.87402967	1.149906012	17.57968917
0.250018625	5.678724223	1.199995784	19.30525612
0.299999813	6.444878086	1.25003205	21.6576704
0.350013156	7.107262797	1.300004957	24.18055723
0.400000755	7.763501947	1.350023126	27.11492951
0.450021865	8.296741786	1.400088518	30.80280115
0.499990618	8.852781554	1.450092337	35.53167756
0.550008272	9.428059603	1.499933424	41.28936168
0.599982679	9.911688618	1.550112005	49.54685951
0.650087968	10.38596569	1.599954912	60.86645043
0.700025127	10.80920788	1.650302972	78.28824889
0.749972209	11.31768634	1.700027693	106.2220024
0.800017684	11.79089462	1.750051073	157.7164686
0.849991894	12.29803709	1.800092657	262.0151559
0.900000461	12.93877873	1.849961979	494.7181995
0.950028231	13.46783147	1.900017198	1071.087888
1.000025804	14.21839163		

Curve

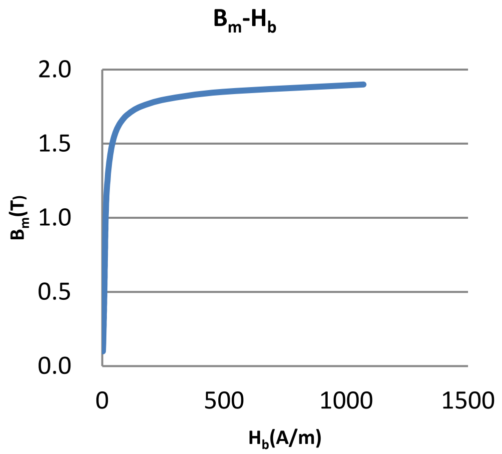


Fig. A2.1 B_m-H_b curve of silicon steel (in rolling direction, B27R090).

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]
0.100017083	165.2033663	0.950017237	293.6888484
0.150007845	210.8840795	0.99998115	300.3634632
0.200005589	233.6921307	1.049990537	309.4695829
0.250005974	245.4061064	1.100044579	322.2844158
0.300014227	251.5837322	1.150003744	346.0330053
0.349983272	255.9764731	1.199969548	390.9704239
0.400004982	259.0225343	1.25025557	475.6188614
0.449986713	261.7853653	1.299971654	641.3459664
0.500009022	264.1260228	1.349982255	992.2910948
0.55001297	266.8193822	1.39971173	1664.588865
0.599972342	269.0745363	1.449826345	2764.237906
0.650007715	271.4312257	1.499641546	4278.246606
0.699997838	274.2742162	1.549538497	6183.370846
0.749990011	277.4805964	1.599682739	8456.741013
0.799994179	280.3984024	1.649973402	11055.59597
0.849963303	284.2727785	1.699267542	13856.10188
0.89997551	288.8632461		

Curve

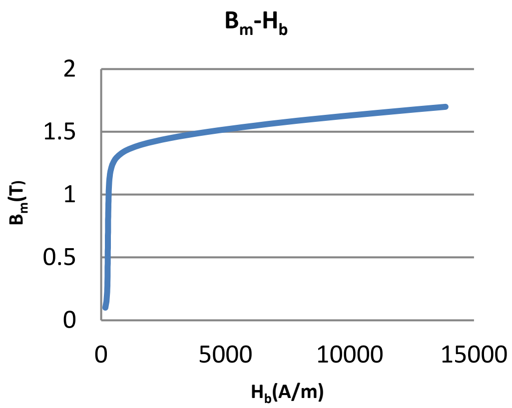


Fig.A2.2 B_m-H_b curve of silicon steel (in transverse direction, B27R090)

2.1.2 W_t-B_m curves

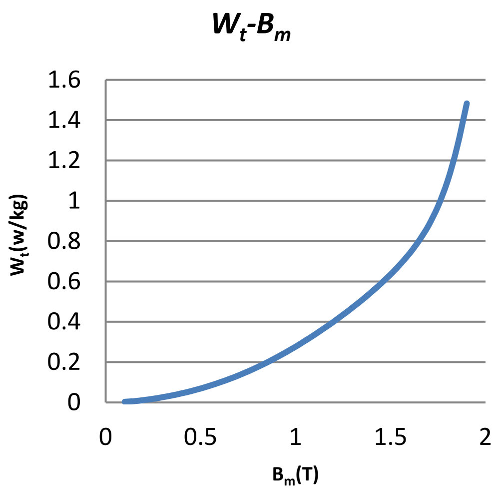
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100008453	0.003213466	1.050158469	0.306049481	
0.150020018	0.006986827	1.099950193	0.336184973	
0.200022134	0.012088933	1.149928593	0.367743601	
0.25002576	0.018535027	1.200020518	0.400758306	
0.300007891	0.026253151	1.250059349	0.435248011	
0.350022088	0.035227537	1.300035352	0.47117578	
0.400010499	0.045443681	1.350057288	0.508746216	
0.450032339	0.056892524	1.400127407	0.548425352	
0.500001777	0.069670431	1.450137012	0.590373333	
0.550020105	0.083704639	1.499985428	0.635238394	
0.599995109	0.099214849	1.550174027	0.684456	
0.65010099	0.116219095	1.600031205	0.739400845	
0.700038736	0.134650192	1.650401158	0.803273386	
0.749986437	0.154590999	1.700161616	0.878080281	
0.80003252	0.176035192	1.7502497	0.973723037	
0.850007397	0.199047694	1.800421478	1.09978189	
0.900016696	0.223685659	1.850583444	1.265569109	
0.950045319	0.24967139	1.90136245	1.483415783	
1.000043913	0.277089942			

Fig. A2.3 W_t -B_m Curve of Silicon Steel in Rolling Direction (B27R090)

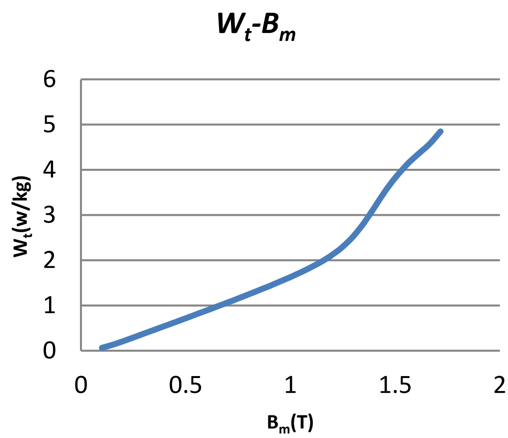
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100224828	0.064768019	0.950385814	1.529983642	
0.150272729	0.130772164	1.000358177	1.630955583	
0.200299154	0.209489487	1.050379052	1.736936191	
0.250314112	0.293265652	1.100449096	1.850297707	
0.300330147	0.378303956	1.150437735	1.975976626	
0.350304673	0.463347995	1.200460043	2.122552684	
0.400330183	0.548173304	1.250852176	2.303877282	
0.450315342	0.63295369	1.300776216	2.534296154	
0.500340657	0.718773309	1.351227799	2.829014126	
0.550347959	0.804945332	1.40180053	3.175410492	
0.600310228	0.891421411	1.45329399	3.533624898	
0.650348567	0.978488843	1.505009052	3.849961998	
0.700342232	1.066373354	1.557295621	4.120730203	
0.750338339	1.155486755	1.610291183	4.350458908	
0.800346299	1.245891079	1.663838072	4.569741371	
0.850320248	1.338592576	1.716666374	4.849313043	
0.90033811	1.432585654			

Fig. A2.4 W_t -B_m Curve of Silicon Steel in Transverse Direction (B27R090)

2.2 Magnetic Properties(Case II)

2.2.1 *B-H* curves

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]
0.100048238	2.971248652	1.049855325	15.58425189
0.15001064	3.962990174	1.09997708	16.7332048
0.200007124	4.884717604	1.149637516	18.22096521
0.250008423	5.687808967	1.199975045	20.02348529
0.300005482	6.455833218	1.249938172	22.03922964
0.350016247	7.16190486	1.299925108	24.54020621
0.400009765	7.821083191	1.350155268	27.65039501
0.450021066	8.400949143	1.399935959	31.18061962
0.500011406	8.927329894	1.449802746	35.75612418
0.549945906	9.528258984	1.500068565	41.77245629
0.600022314	10.02364473	1.55006321	49.52120846
0.649964724	10.50834253	1.599987965	61.04600773
0.700008393	10.94601343	1.649975936	78.30962476
0.75001284	11.47800535	1.699942526	106.5560003
0.799828362	11.94613686	1.749980398	157.9088514
0.850034068	12.48561033	1.799950128	263.0251656
0.900003959	13.0905474	1.849763016	495.3808514
0.950235672	13.87878253	1.900006347	1078.008326
1.000023145	14.52379935		

Curve

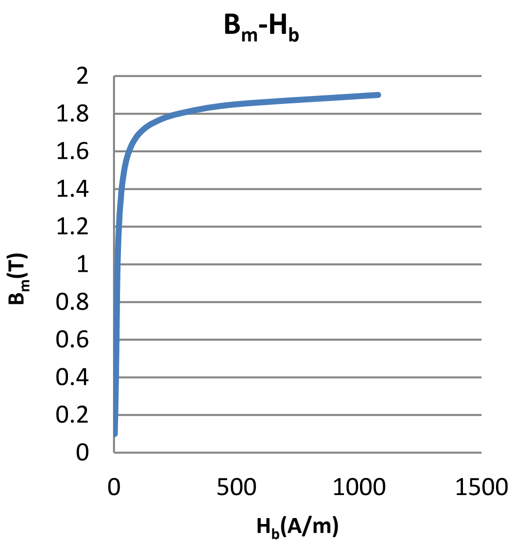


Fig. A2.5 B_m-H_b curve of silicon steel (in rolling direction, B27R090).

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]
0.099997505	165.0457193	0.950007832	293.9667346
0.149983823	211.1726537	0.99994997	299.4977405
0.200042162	234.2265274	1.049989645	308.2084067
0.249981402	245.7160565	1.099994892	321.6003881
0.300001434	252.0807212	1.149998247	344.7130454
0.350006295	256.1848878	1.200015559	390.0405736
0.399996215	259.1026938	1.249983648	473.9301678
0.45001277	262.0632516	1.299955984	637.7013809
0.500017189	264.8528023	1.350024268	989.6992708
0.550005902	266.9903891	1.400007848	1665.230141
0.59998068	269.5448054	1.449763089	2760.924646
0.650001818	272.2755725	1.499596787	4283.483694
0.700030881	274.3917835	1.549636658	6209.770043
0.749990567	277.4538766	1.599536248	8489.873609
0.800015803	280.6549128	1.649517365	11097.81331
0.849956824	284.4811932	1.699391398	13988.89946
0.899982292	288.7510228		

Curve

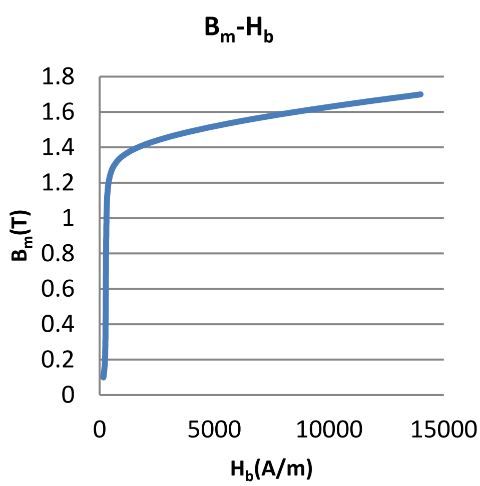


Fig.A2.6 B_m-H_b curve of silicon steel (in transverse direction, B27R090)

2.2.2 W_t-B_m curves

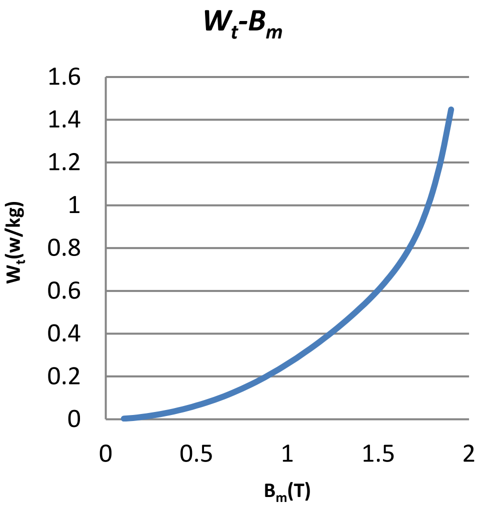
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100051974	0.002985051	1.049875002	0.286070419	
0.150015623	0.006474398	1.09999822	0.315066313	
0.200013242	0.011198559	1.149660496	0.345058472	
0.250015558	0.017151114	1.200000184	0.376947406	
0.300013559	0.024291392	1.249965908	0.410061572	
0.350025207	0.032576373	1.299956057	0.444604741	
0.400019545	0.041963522	1.350190102	0.481354572	
0.450031594	0.052587874	1.399975347	0.519736364	
0.500022621	0.064333622	1.44984788	0.560375453	
0.549957811	0.077353812	1.500121141	0.604752682	
0.600034851	0.091754886	1.550125725	0.652891233	
0.649977876	0.107455984	1.600064543	0.706899399	
0.700022158	0.12455997	1.650073927	0.770003664	
0.750027228	0.143182266	1.700076011	0.845613688	
0.799843382	0.163248952	1.750178845	0.940275792	
0.850049755	0.185006735	1.800279916	1.064847893	
0.900020411	0.208094284	1.850385415	1.229904174	
0.950253014	0.232768457	1.901353965	1.448224159	
1.000041563	0.258713405			

Fig. A2.7 W_t -B_m Curve of Silicon Steel in Rolling Direction (B27R090)

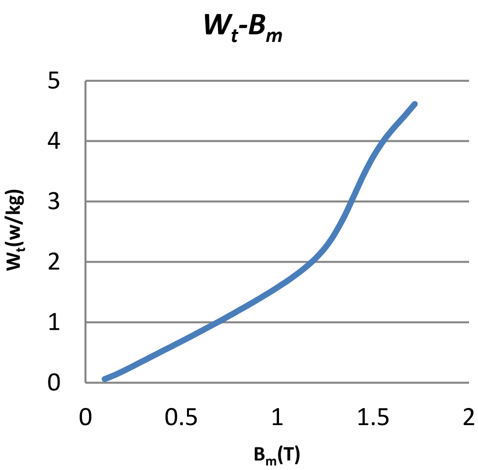
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100204956	0.061761297	0.950376828	1.477364168	
0.150249132	0.124474228	1.000325883	1.576885268	
0.200336335	0.199423419	1.050376783	1.681930005	
0.250289932	0.279361636	1.100398895	1.794236174	
0.300317942	0.360835407	1.150431614	1.918275723	
0.350327901	0.442203422	1.200505409	2.062777829	
0.400321457	0.523330923	1.250577936	2.24080834	
0.450341769	0.60451929	1.30075651	2.471108003	
0.500349713	0.686067514	1.351264473	2.765534156	
0.550341113	0.768758153	1.402097857	3.112325223	
0.60031907	0.852512467	1.453229156	3.461979939	
0.650343586	0.937108914	1.504972687	3.769657237	
0.700375402	1.022699219	1.557431455	4.022324483	
0.750338819	1.109530897	1.610192036	4.228679011	
0.800368182	1.198173162	1.663435591	4.417343061	
0.85031388	1.288303234	1.716936626	4.6172479	
0.900344761	1.381337817			

Fig. A2.8 W_t -B_m Curve of Silicon Steel in Transverse Direction (B27R090)

2.3 Magnetic Properties (Case III)

2.3.1 *B-H* curves

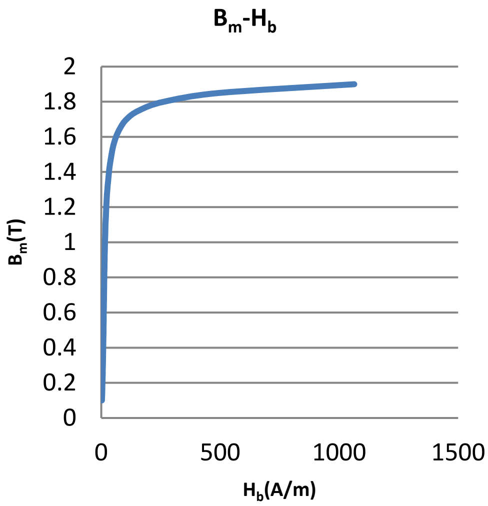
B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]	Curve
0.100021813	3.039063594	1.050002638	16.55845707	
0.150006549	4.095627435	1.099756451	17.72771706	
0.200002569	5.033600525	1.149952915	19.46183435	
0.250002912	5.938537211	1.200038618	21.07197161	
0.299984272	6.676539056	1.250040509	23.19245773	
0.349923062	7.440905469	1.299864391	25.54166563	
0.40000047	8.124933247	1.349959946	28.87042268	
0.450028062	8.724259147	1.400066173	32.45729334	
0.499994144	9.356717643	1.44996041	37.02915117	
0.550013969	9.921842155	1.500042365	43.08279701	
0.600017617	10.47841632	1.550047754	50.64023516	
0.650035685	11.04300643	1.599955233	61.86149709	
0.699998302	11.56270723	1.650043863	79.12725171	
0.749998605	12.02816675	1.699935244	105.636838	
0.80000744	12.6526093	1.750081485	157.5267577	
0.850036263	13.20063312	1.800058997	261.4593833	
0.900014203	13.90090228	1.849907294	492.2599747	
0.950006993	14.63676654	1.900055606	1063.793373	
0.999888914	15.60028379			

Fig. A2.9 B_m-H_b curve of silicon steel (in rolling direction, B27R090).

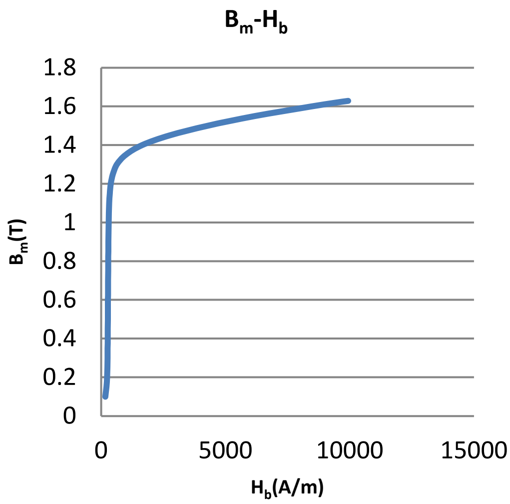
B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]	Curve
0.100017579	167.9207736	0.949986504	296.018818	
0.149998379	214.9187746	0.99989202	302.4155465	
0.200010308	238.656676	1.049951594	311.1369007	
0.250029454	250.648538	1.099993	324.4059707	
0.299961909	257.13077	1.149955842	346.7544408	
0.349988869	260.3104304	1.199989287	387.6464764	
0.399986677	263.3725235	1.250082558	471.5574464	
0.449995008	266.2422338	1.299843867	633.7361574	
0.50003625	268.801994	1.350096193	990.313827	
0.550027533	270.907517	1.399938957	1653.152776	
0.599984235	273.2161107	1.449897444	2746.923453	
0.650007404	275.7544951	1.499846436	4270.551293	
0.699983971	278.6135174	1.549536855	6173.00355	
0.750065015	281.5580432	1.599423024	8447.121873	
0.800015524	283.220017	1.61672975	9306.431769	
0.850016006	286.944762	1.628635776	9938.355868	
0.900021949	290.9206734			

Fig.A2.10 B_m-H_b curve of silicon steel (in transverse direction, B27R090)

2.3.2 W_t-B_m curves

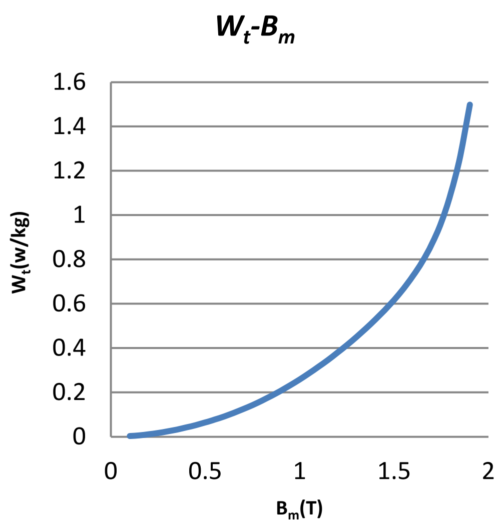
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100025641	0.002970172	1.050023554	0.286464736	
0.150011689	0.006447488	1.099778886	0.315644563	
0.200008882	0.011159634	1.149977273	0.346592793	
0.250010365	0.017087675	1.200065201	0.379192601	
0.299992655	0.024225307	1.250069776	0.413584656	
0.349932346	0.032520452	1.299896792	0.449655679	
0.400010588	0.041993952	1.349996167	0.487577979	
0.450038996	0.052642829	1.40010701	0.528022095	
0.500005883	0.064392827	1.450007028	0.571192039	
0.550026427	0.077419236	1.50009628	0.617146436	
0.600030769	0.091669706	1.550111432	0.668030877	
0.650049484	0.107380205	1.600032941	0.725226289	
0.700012784	0.124393347	1.65014312	0.790256165	
0.750013768	0.142835405	1.700068255	0.868857944	
0.800023323	0.162934773	1.75027937	0.9668693	
0.850052879	0.184500908	1.800386578	1.096486874	
0.900031697	0.207715867	1.85052549	1.266337724	
0.950025433	0.232496933	1.901392295	1.498442443	
0.999908485	0.258538144			

Fig. A2.11 W_t -B_m Curve of Silicon Steel in Rolling Direction (B27R090)

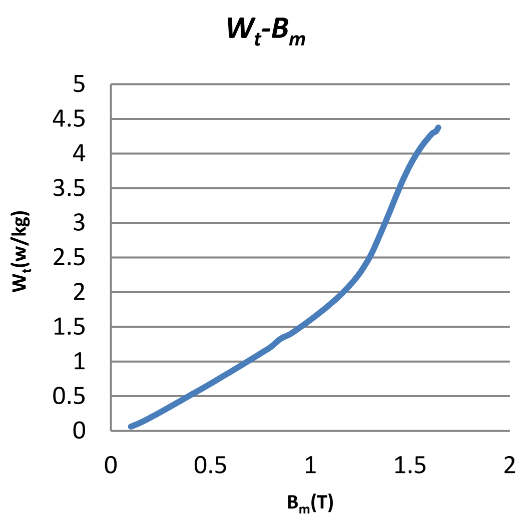
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100228462	0.060679708	0.950358129	1.497703235	
0.150268121	0.121693297	1.00027175	1.601713239	
0.200309947	0.194950486	1.050342217	1.711828034	
0.250344066	0.273771478	1.100400072	1.829537067	
0.300284237	0.354529576	1.150390974	1.959435499	
0.350315598	0.435923847	1.200475323	2.108166143	
0.400317301	0.517703541	1.250675658	2.28995092	
0.450329212	0.599802069	1.300640404	2.523775367	
0.500373717	0.682386047	1.351339554	2.844614002	
0.550367669	0.768098586	1.402013285	3.191054358	
0.600327316	0.853584535	1.453350349	3.550052803	
0.650353659	0.940094325	1.505210249	3.861707266	
0.70033367	1.027598426	1.557294248	4.102199069	
0.750418462	1.117173937	1.61003214	4.288028232	
0.800370985	1.208413503	1.628416197	4.317893281	
0.850376228	1.327939448	1.641101287	4.376727002	
0.900387171	1.398241447			

Fig. A2.12 W_t -B_m Curve of Silicon Steel in Transverse Direction (B27R090)

2.4 Magnetic Properties(Case IV)

2.4.1 *B-H* curves

As mentioned above, the initial magnetization *B-H* curves are recommended to be used in Case IV and V due to the consideration of the feasibility of the 3-D transient calculation (with DC-bias).

B [T]	*H* [A/m]	*B* [T]	*H* [A/m]	Curve
0.034613644	4.392352272	1.144132303	16.3828105	
0.239500343	5.14847444	1.14416046	17.77780499	
0.280571392	5.803612732	1.215773664	19.33268029	
0.330653364	6.486208327	1.261208571	21.45002522	
0.380742348	7.072150796	1.312197759	24.11559596	
0.425231008	7.651497742	1.334881378	27.47425786	
0.479177073	8.231296787	1.403817594	31.53633544	
0.522190343	8.77742884	1.422775606	36.71534488	
0.589952366	9.325770623	1.491253512	43.27019924	
0.635503419	9.850981152	1.551442681	51.8564793	
0.696426703	10.40620329	1.593906185	63.87709182	
0.742007361	10.9949802	1.646445169	81.5338271	
0.807984884	11.62362845	1.697507608	109.2971882	
0.863904029	12.22248943	1.747641103	157.6954133	
0.911731214	12.92055581	1.799666179	252.7948889	
1.014894169	13.62763746	1.851106746	464.3965306	
1.073494206	14.47248123	1.882815177	996.2568528	
1.056623641	15.35924309			

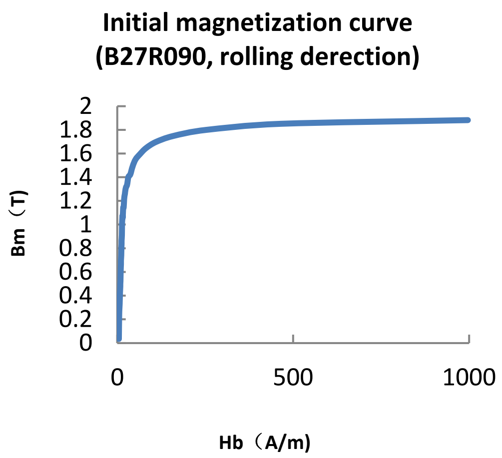


Fig.A2.13 Initial magnetization *B-H* curve of silicon steel (in rolling direction, B27R090)

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]	Curve
0.0950471	155.4528176	0.9308006	295.8550788	
0.145940272	202.048685	0.982553789	303.7840296	
0.190697539	225.783487	1.035742331	315.442428	
0.236419706	239.4089997	1.08753488	331.77466	
0.282676719	247.2581116	1.142844667	358.7251407	
0.325085612	252.2126103	1.19657356	402.3150246	
0.367585157	256.1977134	1.247461547	477.6835565	
0.415050077	259.6291815	1.296077238	623.7991747	
0.460052135	262.5373683	1.350996136	983.423316	
0.513020104	265.5142786	1.400546505	1630.753538	
0.563593314	268.2377779	1.450572111	2695.738937	
0.613842126	271.0523385	1.500224699	4171.566061	
0.667094867	274.110477	1.550240131	6041.520586	
0.721825875	277.5010104	1.600006906	8283.209045	
0.772892937	280.9862388	1.650051761	10824.04188	
0.826208456	285.0693502	1.657756764	11223.97368	
0.877100417	289.7226629			

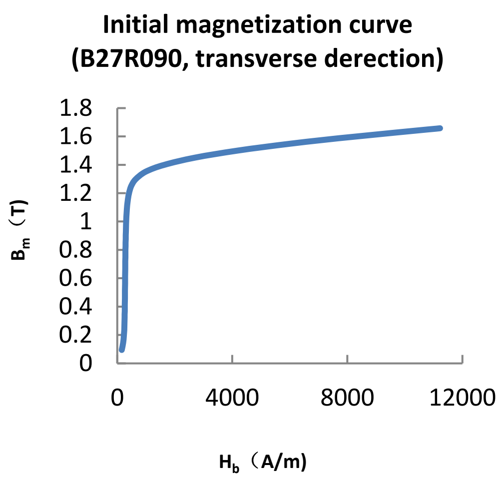


Fig.A2.14 Initial magnetization *B-H* curve of silicon steel (in transverse direction, B27R090)

2.4.2 W_t-B_m curves with different DC-biases (in rolling direction)

See Figs. A2.15-30 for the measured W_t-B_m curves under AC-DC hybrid excitations.

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.099997094	0.002932884	1.049988788	0.305364506
0.150014806	0.006584082	1.100075633	0.332470425
0.200004825	0.011789214	1.150118574	0.360771548
0.249998707	0.018462137	1.199980364	0.391070001
0.300016054	0.027414803	1.25006471	0.423320057
0.350009979	0.037651814	1.300040081	0.457132665
0.399998157	0.051403248	1.350027123	0.493253751
0.449992581	0.064474716	1.399770335	0.531340129
0.500005153	0.079657344	1.449986038	0.572490994
0.550003132	0.096390747	1.500020714	0.616679881
0.599980352	0.112999632	1.549726989	0.664380752
0.649979316	0.131022454	1.599866872	0.717108576
0.70000865	0.150023795	1.650009304	0.778348355
0.750002974	0.169579701	1.699846221	0.850786665
0.799977813	0.190047575	1.749978649	0.943257662
0.850019594	0.211317151	1.799957196	1.064792977
0.899992001	0.232932571	1.850028692	1.23011362
0.949984077	0.256071712	1.900075981	1.447518691
0.999982685	0.280095495		

Curve

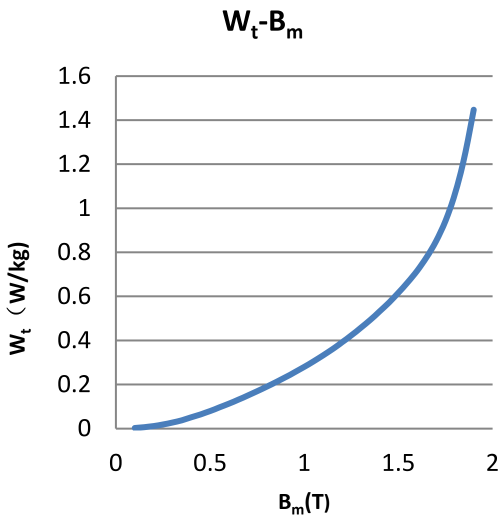


Fig. A2.15 W_t-B_m curve of silicon steel with 5A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.100032807	0.004148486	1.050026054	0.338069619
0.150002619	0.009363303	1.099989863	0.364830407
0.200003897	0.017211149	1.15002504	0.392496121
0.249974542	0.027386817	1.200032786	0.4221888
0.299986399	0.039249085	1.249961847	0.454124657
0.349999335	0.052098247	1.299954164	0.487334056
0.400001662	0.066787339	1.350007265	0.522467403
0.450010971	0.082230205	1.399997592	0.559862528
0.499989333	0.099379893	1.449975194	0.600472363
0.550022636	0.117090638	1.499992866	0.642882692
0.600006566	0.135809897	1.55008216	0.689510094
0.650018266	0.155079648	1.599940005	0.73934293
0.69997227	0.175166124	1.6499532	0.796251168
0.750023906	0.196051094	1.699924484	0.864337697
0.800032522	0.218077556	1.75007067	0.950116646
0.849997231	0.240170619	1.799909495	1.067076428
0.899990627	0.263295418	1.849878203	1.228600233
0.950045133	0.287463308	1.899956682	1.446388237
1.000011954	0.312388981		

Curve

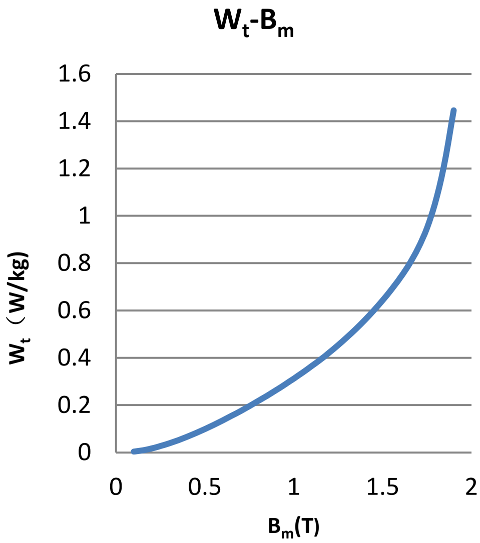


Fig. A2.16 W_t-B_m curve of silicon steel with 10A/m DC bias (in rolling direction, B27R090)

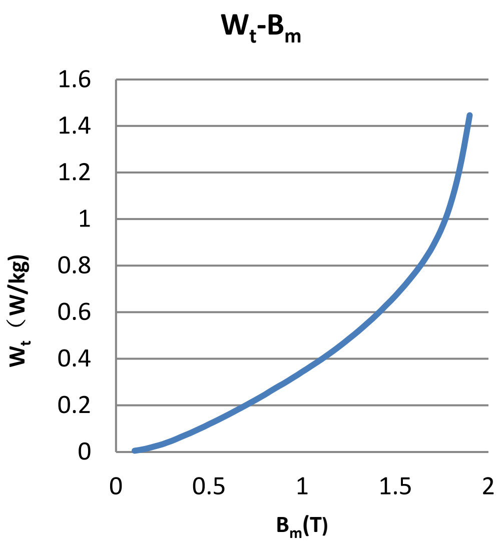
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100032807	0.005323414	1.050026054	0.369973619	
0.150002619	0.012120489	1.099989863	0.396330162	
0.200003897	0.022170102	1.15002504	0.424450774	
0.249974542	0.033685569	1.200032786	0.454080755	
0.299986399	0.048090836	1.249961847	0.485346455	
0.349999335	0.064651787	1.299954164	0.518256953	
0.400001662	0.081602031	1.350007265	0.552883224	
0.450010971	0.100200859	1.399997592	0.589752248	
0.499989333	0.119131485	1.449975194	0.629264772	
0.550022636	0.138725959	1.499992866	0.67037546	
0.600006566	0.15912396	1.55008216	0.715421648	
0.650018266	0.180223924	1.599940005	0.763795167	
0.69997227	0.201768674	1.6499532	0.81779644	
0.750023906	0.223846452	1.699924484	0.881858879	
0.800032522	0.246645631	1.75007067	0.962661681	
0.849997231	0.27146913	1.799909495	1.073133169	
0.899990627	0.293953894	1.849878203	1.231361918	
0.950045133	0.318553968	1.899956682	1.446327897	
1.000011954	0.343814632			

Fig. A2.17 W_t-B_m curve of silicon steel with 15A/m DC bias (in rolling direction, B27R090)

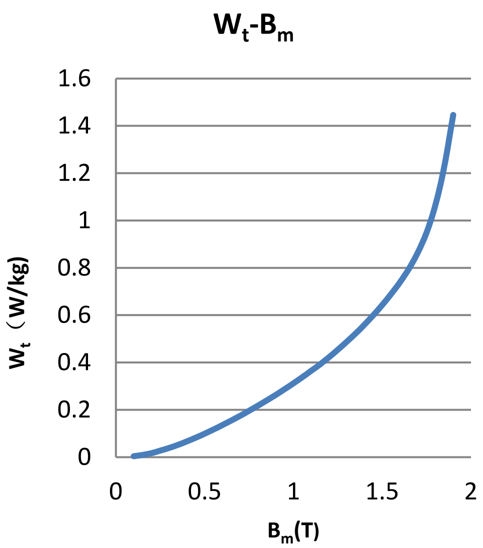
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100001369	0.006863522	1.050022704	0.395740199	
0.14999891	0.015484035	1.100005405	0.422844079	
0.200004784	0.027342485	1.149952812	0.450677248	
0.250007288	0.042728881	1.199981877	0.480391744	
0.300000613	0.058784531	1.250002049	0.510839269	
0.350029211	0.076164899	1.299985832	0.543476049	
0.400014505	0.09531125	1.350049554	0.579583407	
0.449992638	0.115315834	1.399993985	0.614772622	
0.499985463	0.137044631	1.450068979	0.652979586	
0.550030874	0.15849609	1.499946288	0.693772109	
0.600004324	0.179916459	1.549984378	0.737318838	
0.6500088	0.202574368	1.600044886	0.78447688	
0.700001425	0.22475586	1.649977164	0.836861749	
0.750005759	0.247694775	1.699855966	0.897007217	
0.800029356	0.271380867	1.750053117	0.973553722	
0.85008131	0.295285071	1.799965912	1.07887408	
0.899980811	0.319415433	1.849919851	1.232244166	
0.950022128	0.344289502	1.899999058	1.446181966	
0.999983863	0.369999986			

Fig. A2.18 W_t-B_m curve of silicon steel with 20A/m DC bias (in rolling direction, B27R090)

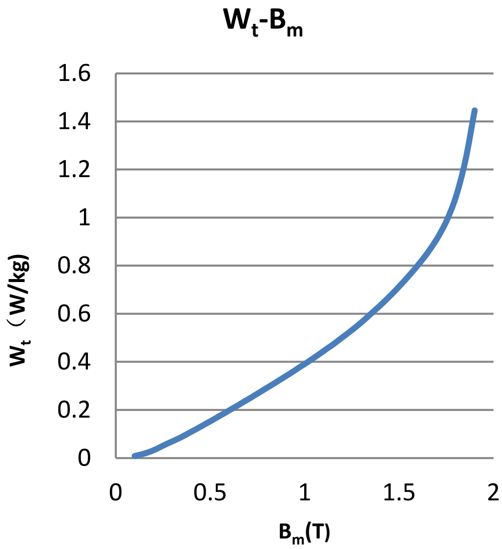
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099999273	0.008451421	1.049828512	0.417650681	
0.149998754	0.018425485	1.100018648	0.444932825	
0.200009512	0.03222541	1.14996706	0.472679274	
0.250012207	0.0515091	1.199999539	0.502523284	
0.300011353	0.069929185	1.249993931	0.531970325	
0.349975751	0.088604477	1.299933209	0.564518512	
0.399996498	0.109516019	1.350003757	0.599464424	
0.450022922	0.130830079	1.39994366	0.635087559	
0.50001045	0.152841843	1.44982444	0.672958748	
0.549992538	0.175369564	1.500083765	0.713356109	
0.599985335	0.197974076	1.550027432	0.756548061	
0.650129106	0.220931348	1.600012857	0.802606356	
0.700005495	0.244325356	1.650041296	0.853335588	
0.750003988	0.267849742	1.700054418	0.911929419	
0.799988825	0.292071631	1.750033573	0.984712561	
0.849993768	0.316083904	1.799949887	1.085066408	
0.899972458	0.340605692	1.849989495	1.234705881	
0.949998123	0.365785237	1.899943569	1.445757092	
0.999832767	0.391537584			

Fig. A2.19 W_t-B_m curve of silicon steel with 25A/m DC bias (in rolling direction, B27R090)

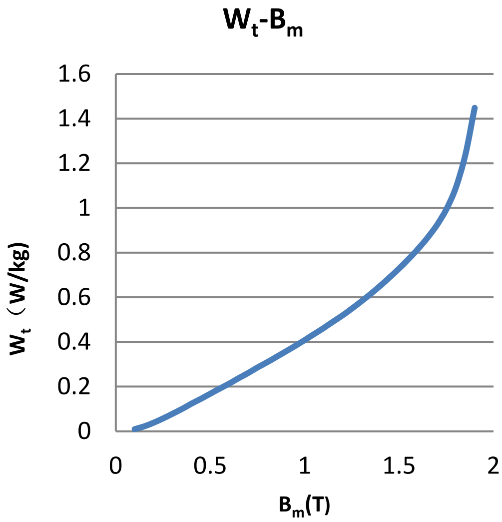
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.09999978	0.009810494	1.050022127	0.435491148	
0.150005026	0.022227546	1.09998786	0.462350408	
0.200003408	0.038363954	1.149982434	0.490793453	
0.249991535	0.057735129	1.199969869	0.519149784	
0.300008066	0.078483745	1.250036267	0.549596359	
0.350014345	0.099760104	1.300039491	0.581990373	
0.400018308	0.123638227	1.350000545	0.615812335	
0.450006231	0.145449324	1.399968946	0.651850152	
0.500005795	0.168273672	1.449997496	0.689368574	
0.550003895	0.191235908	1.499935137	0.729210787	
0.59999365	0.213681535	1.55000178	0.77125364	
0.649984519	0.238086545	1.599964675	0.816396112	
0.699742803	0.260907123	1.65002596	0.866719677	
0.750034713	0.285700655	1.699994603	0.923482757	
0.800005309	0.308592544	1.750027736	0.994114817	
0.849972066	0.332919181	1.799899305	1.090563077	
0.899985005	0.357684156	1.849941686	1.236228215	
0.949963499	0.382737909	1.899879688	1.448324035	
0.99996432	0.40868057			

Fig. A2.20 W_t-B_m curve of silicon steel with 30A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099995931	0.011772656	1.049981114	0.450609108	
0.150003594	0.026178178	1.100034584	0.477115993	
0.20000628	0.0451823	1.150026018	0.505021416	
0.249988511	0.065540057	1.200007196	0.534278076	
0.300005515	0.087587786	1.249975977	0.56517789	
0.349999802	0.110177808	1.299942313	0.596269101	
0.400001384	0.134569613	1.350002337	0.631304434	
0.449977863	0.157257384	1.400039624	0.667216036	
0.500010621	0.181209945	1.450019981	0.703590525	
0.550002447	0.204662915	1.500068981	0.74313188	
0.599997	0.228049087	1.549734603	0.78555072	
0.649990781	0.251529335	1.600047085	0.830480933	
0.700000153	0.275912728	1.649971909	0.879080529	
0.750008985	0.299619095	1.699979417	0.934769756	
0.800006553	0.323386034	1.749988122	1.003521597	
0.850006868	0.347669711	1.799964887	1.097008721	
0.899985933	0.373401433	1.849938383	1.239794654	
0.949973975	0.398152246	1.899931887	1.4487623	
0.999985023	0.423892362			

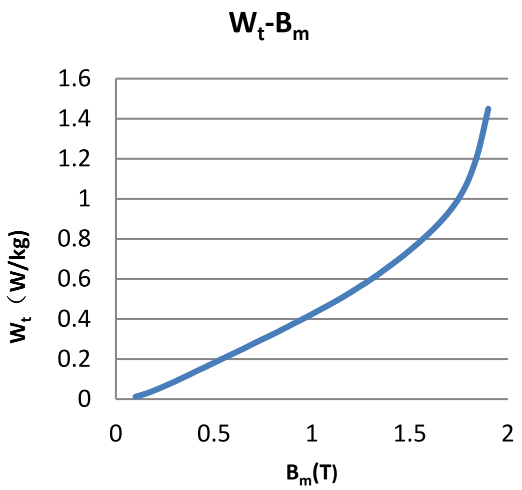


Fig. A2.21 W_t-B_m curve of silicon steel with 35A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099996429	0.01402004	1.049958947	0.463769508	
0.150005883	0.032206768	1.100003137	0.490560991	
0.200003874	0.051577124	1.149976259	0.518354795	
0.250008145	0.073462373	1.200031139	0.546839053	
0.300008379	0.096525781	1.24994782	0.577107815	
0.350010723	0.120198887	1.300009377	0.60918383	
0.400016061	0.144152186	1.350060495	0.642860575	
0.450007662	0.168346521	1.400060045	0.678858814	
0.499991316	0.19246585	1.450052965	0.715897123	
0.550017459	0.215863462	1.50002963	0.754982129	
0.600023024	0.239352623	1.549988059	0.81292883	
0.649974747	0.262946568	1.599924309	0.857959961	
0.699999569	0.286937374	1.64993565	0.905303642	
0.749975632	0.311251236	1.700002191	0.959872252	
0.80000186	0.337192485	1.749919369	1.024171117	
0.849931779	0.361871601	1.799962521	1.111383993	
0.899991644	0.386462613	1.849873186	1.243837095	
0.949991858	0.412263061	1.899763665	1.448353182	
0.999998908	0.437549309			

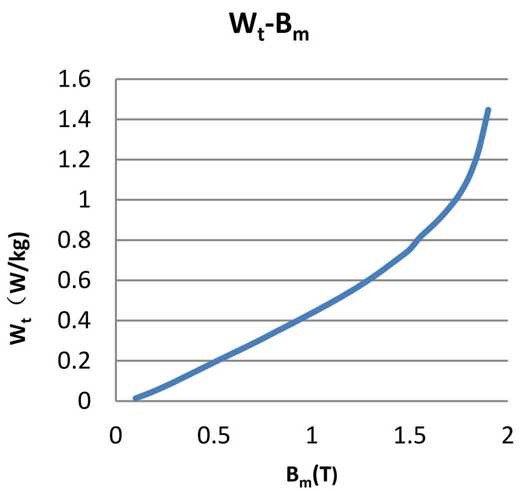


Fig. A2.22 W_t-B_m curve of silicon steel with 40A/m DC bias (in rolling direction, B27R090)

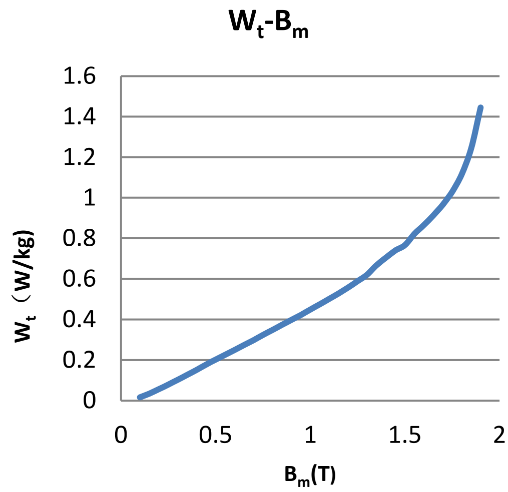
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100001501	0.016288322	1.050027472	0.474784826	
0.150001909	0.034633726	1.099954177	0.501516442	
0.199996864	0.056621944	1.150005531	0.528997993	
0.250012802	0.079288074	1.200011996	0.558088173	
0.30000588	0.103204406	1.250007685	0.589134525	
0.349989931	0.127226831	1.29998551	0.620883859	
0.40000472	0.152034984	1.3499658	0.667728998	
0.450007987	0.177979742	1.399997621	0.704922659	
0.500014003	0.202619689	1.449960037	0.740891061	
0.549992338	0.225803374	1.499968522	0.766459259	
0.599995945	0.249669004	1.550042764	0.821992481	
0.650000521	0.274164573	1.600025195	0.865228381	
0.700013409	0.297917828	1.649921219	0.913563482	
0.75003662	0.323989338	1.700015632	0.96595594	
0.79997988	0.34857663	1.750054721	1.030040331	
0.849994839	0.373146239	1.799949614	1.115689906	
0.900022788	0.397902308	1.849867917	1.243433998	
0.950009456	0.422517879	1.900070698	1.445252573	
1.000048274	0.449128167			

Fig. A2.23 W_t-B_m curve of silicon steel with 45A/m DC bias (in rolling direction, B27R090)

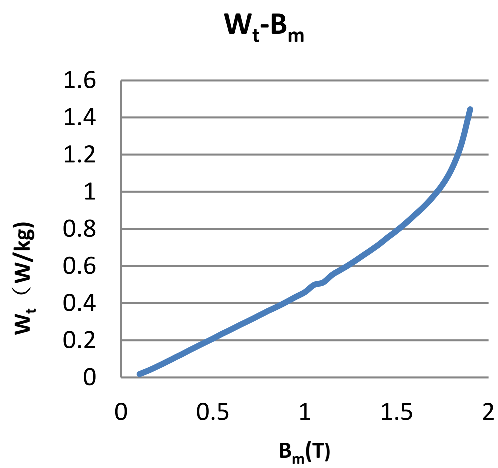
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100004192	0.018730879	1.050018393	0.498227644	
0.14999717	0.038330956	1.100003161	0.512196463	
0.199999742	0.06184754	1.150005953	0.553766969	
0.249997648	0.085365063	1.200016375	0.582850747	
0.300007854	0.110318089	1.250005404	0.613162307	
0.349993369	0.135634906	1.299966479	0.645965896	
0.400013777	0.160925295	1.349994476	0.67982665	
0.450029015	0.185622001	1.400041095	0.71402968	
0.499996684	0.209934683	1.44997375	0.753128852	
0.550000922	0.235286768	1.500036997	0.791031431	
0.599992672	0.259937549	1.549947343	0.831843518	
0.649981842	0.284697584	1.600161278	0.876410906	
0.700002858	0.308753216	1.650003843	0.92251361	
0.750001875	0.333522543	1.700087669	0.975705441	
0.800011705	0.35850596	1.749882381	1.039183334	
0.850010331	0.382100133	1.799983359	1.123981342	
0.899999212	0.407445175	1.849992022	1.247809236	
0.949965498	0.434104847	1.899802621	1.445009135	
1.000015024	0.459627935			

Fig. A2.24 W_t-B_m curve of silicon steel with 50A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.0999987	0.024003553	1.050009538	0.514704507	
0.15000617	0.046073986	1.099918414	0.542697204	
0.199992906	0.070547821	1.149950687	0.570571103	
0.249999214	0.0958908	1.199946991	0.598536093	
0.300007522	0.122297865	1.250066524	0.628891694	
0.350003065	0.147890638	1.299846293	0.661919928	
0.399995243	0.173506188	1.350003065	0.695666165	
0.450015838	0.199271117	1.40002445	0.731308929	
0.499994323	0.225761571	1.449978727	0.767065538	
0.550003488	0.250950207	1.499985386	0.809547659	
0.599998295	0.275526446	1.550046995	0.850307348	
0.650010978	0.300481774	1.599980435	0.893134995	
0.700001161	0.324615292	1.650086576	0.940206894	
0.750000587	0.349407529	1.699958212	0.993239386	
0.799982785	0.374569109	1.749885692	1.054397998	
0.849961304	0.39956775	1.79986067	1.134207338	
0.900030818	0.437317061	1.849846385	1.254003363	
0.949993083	0.462777991	1.899799705	1.445992271	
1.000088376	0.485493079			

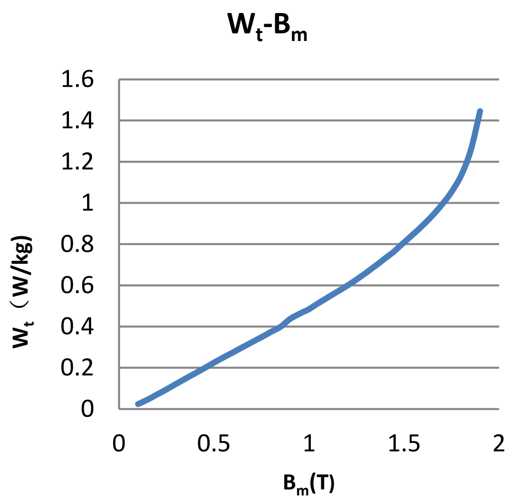


Fig. A2.25 W_t-B_m curve of silicon steel with 60A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099982791	0.026873433	1.050007119	0.527485343	
0.150012713	0.052095602	1.099976985	0.555463933	
0.200009359	0.078630348	1.149983335	0.58304175	
0.249991513	0.105943349	1.200004974	0.613697354	
0.300003734	0.132987002	1.250016405	0.643981784	
0.350002307	0.159981631	1.300003299	0.676227509	
0.399992727	0.186357534	1.349977863	0.710285071	
0.449999243	0.212089284	1.399989038	0.746214982	
0.500021818	0.237488801	1.450080821	0.782500031	
0.550011883	0.262701905	1.500066552	0.821436699	
0.600012771	0.286681063	1.550007103	0.862671978	
0.649994879	0.311559123	1.60001347	0.906176912	
0.699977467	0.337080162	1.649786537	0.952292146	
0.750038514	0.362877729	1.699956198	1.004321906	
0.800034682	0.397279292	1.75001906	1.064169528	
0.849982597	0.422981958	1.80007827	1.143225602	
0.900029204	0.449107067	1.850005472	1.258961843	
0.949990405	0.475282502	1.899785268	1.446696327	
1.000019426	0.501554749			

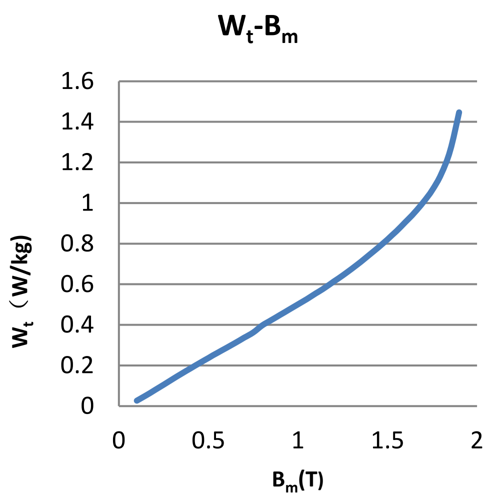


Fig. A2.26 W_t-B_m curve of silicon steel with 70A/m DC bias (in rolling direction, B27R090)

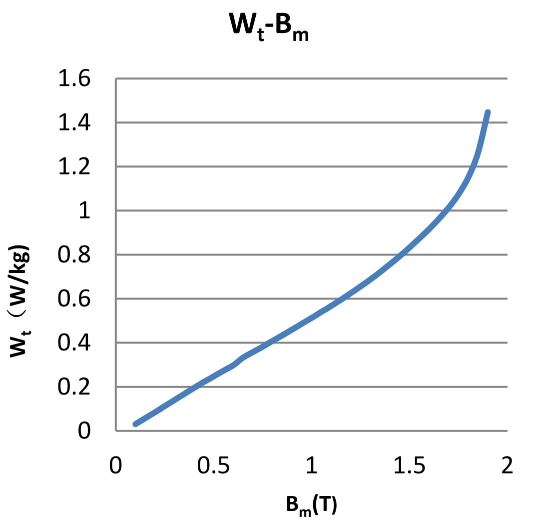
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.1000042	0.030512166	1.049951324	0.540688072	
0.14999842	0.057989719	1.099998218	0.567622792	
0.200008473	0.08490057	1.149999148	0.596074106	
0.250001635	0.112988353	1.199964913	0.625484215	
0.300008282	0.140617718	1.249981876	0.656298262	
0.350017415	0.168427441	1.299995001	0.687358616	
0.399996435	0.19590591	1.350056865	0.721463815	
0.449990557	0.222238629	1.400023903	0.756972033	
0.500018896	0.248032079	1.449942944	0.793464065	
0.55002142	0.273432451	1.499985796	0.832821695	
0.599988391	0.298406531	1.55004613	0.874152628	
0.649974033	0.332832372	1.599994316	0.916584222	
0.699985668	0.35798925	1.650003263	0.963069646	
0.749950667	0.382702174	1.69996977	1.013817924	
0.79999462	0.408763364	1.750107611	1.074539757	
0.849893983	0.434034327	1.800022253	1.151262236	
0.900001043	0.460241719	1.849983268	1.263710241	
0.950078717	0.486651813	1.899935968	1.447540953	
1.00000619	0.513183333			

Fig. A2.27 W_t-B_m curve of silicon steel with 80A/m DC bias (in rolling direction, B27R090)

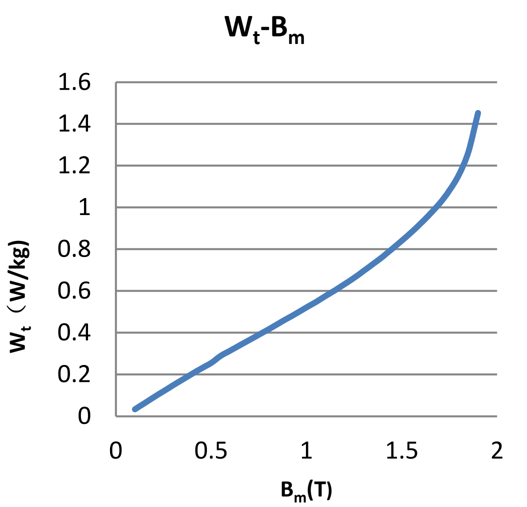
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099988892	0.033367532	1.050000702	0.547901328	
0.149997623	0.062822776	1.100011196	0.575852803	
0.20001337	0.091856375	1.150009944	0.603748548	
0.250005949	0.120049237	1.199963445	0.63303176	
0.300010212	0.148221375	1.249966888	0.663182121	
0.349997989	0.175822352	1.29999335	0.696247062	
0.400014169	0.203338746	1.350009533	0.730023421	
0.450004182	0.229912011	1.400073787	0.764625521	
0.499989971	0.255721418	1.449981015	0.802312968	
0.55000435	0.289383784	1.499993144	0.841213392	
0.599991834	0.31454058	1.550023163	0.88091212	
0.650015459	0.340249813	1.599989933	0.924537998	
0.700004793	0.365197785	1.649837281	0.97067837	
0.750004983	0.390633218	1.700002727	1.021069503	
0.800069571	0.415895505	1.750066495	1.081534378	
0.849963993	0.442879172	1.799887895	1.157381422	
0.900046736	0.468741524	1.849934147	1.268772484	
0.949948268	0.494384645	1.899781711	1.452888016	
1.000010492	0.521360156			

Fig. A2.28 W_t-B_m curve of silicon steel with 90A/m DC bias (in rolling direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.099995555	0.036262585	1.049907363	0.556980313	
0.150004292	0.067295576	1.099898347	0.584188491	
0.200004476	0.097017497	1.149982679	0.612548897	
0.250004784	0.126029177	1.199912399	0.642241132	
0.299996415	0.154654024	1.250004422	0.67270763	
0.350003144	0.182852577	1.300001668	0.704679518	
0.400002745	0.210494812	1.350008755	0.738053139	
0.449992566	0.244408646	1.400001631	0.773903123	
0.499925931	0.270446151	1.450012996	0.811033923	
0.550014747	0.296487443	1.500004465	0.85008721	
0.599987857	0.322287952	1.549994373	0.890579444	
0.650029391	0.347925531	1.599860518	0.9331104	
0.699977119	0.374674208	1.64999145	0.979157526	
0.749995922	0.400009132	1.700038803	1.02970343	
0.799952718	0.425847611	1.749736697	1.089181465	
0.849979739	0.451236983	1.799767158	1.163871384	
0.899932041	0.477298487	1.849928638	1.273579198	
0.949951335	0.503638604	1.899622884	1.453450183	
1.000035584	0.530158778			

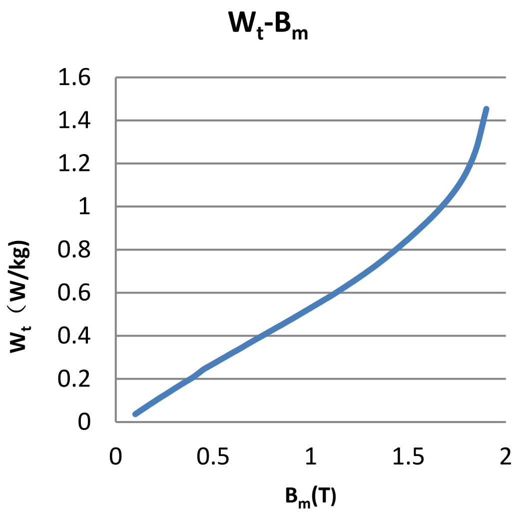


Fig. A2.29 W_t-B_m curve of silicon steel with 100A/m DC bias (in rolling direction, B27R090)

Fig.A2.30 shows the comparison of the W_t-B_m curves with different DC-biases in rolling directions.

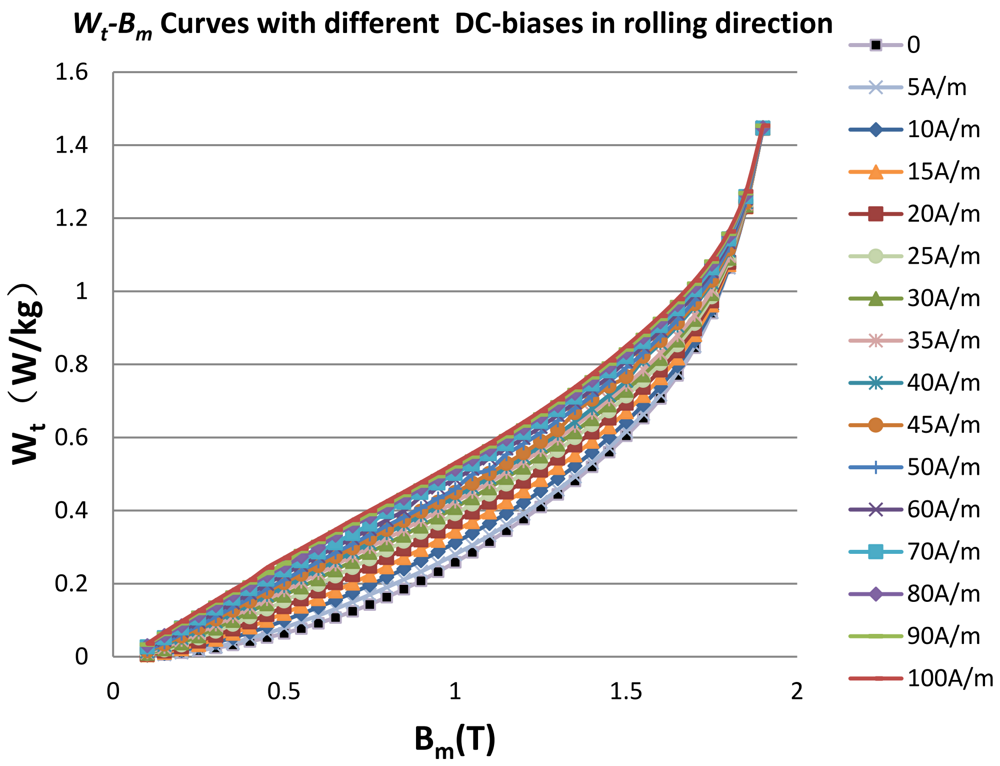


Fig. A2.30 W_t-B_m curves of silicon steel with different DC-biases (in rolling direction, B27R090)

2.4.3 W_t-B_m curves with different DC-biases (in transverse direction)

See Figs. A2.31-46 for the measured W_t-B_m curves under AC-DC hybrid excitations.

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.100007353	0.0614354	0.950000744	1.476202655
0.149991882	0.124147593	0.999854612	1.574695395
0.199962934	0.199241105	1.050028481	1.679603589
0.250008155	0.279395611	1.100025197	1.792907246
0.300005255	0.360943458	1.150028409	1.91633949
0.350006452	0.442426192	1.199910509	2.06152613
0.399965403	0.523818039	1.249981042	2.23992038
0.450019024	0.606622476	1.299950308	2.469984257
0.500024599	0.689170629	1.349996569	2.761814972
0.550031816	0.77222377	1.400044567	3.107501262
0.599976782	0.855391317	1.450013702	3.457824395
0.649895291	0.939363779	1.499969726	3.763997008
0.700044345	1.024629495	1.549835549	4.016039641
0.749930785	1.111288827	1.600040544	4.222375932
0.800002824	1.19893046	1.650054215	4.413882456
0.849965819	1.288831353	1.699979505	4.613352701
0.900008814	1.381503926		

Curve

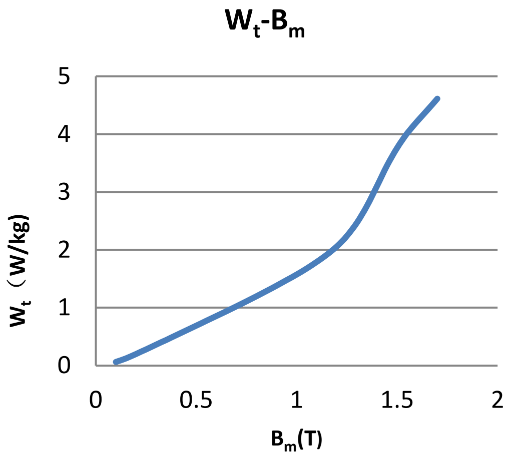


Fig. A2.31 W_t-B_m curve of silicon steel with 5A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.100002123	0.061103184	0.950034496	1.473336559
0.150008102	0.124018871	1.00000478	1.572260948
0.200013458	0.198983618	1.05001763	1.674976099
0.249999514	0.278977332	1.099950238	1.786946261
0.300010565	0.360404838	1.149982518	1.911492568
0.350002647	0.441815233	1.199981542	2.054184078
0.399994482	0.52275323	1.249964801	2.232607744
0.450003147	0.604173447	1.300417829	2.460995744
0.499983826	0.686298399	1.349932484	2.754299317
0.5500098	0.770500106	1.399929676	3.102646583
0.600030538	0.853983733	1.450016308	3.457648585
0.649992784	0.937705845	1.499985717	3.770831029
0.699992059	1.022686538	1.550016736	4.029482116
0.750033758	1.108484189	1.599983334	4.246758872
0.799987361	1.196617449	1.649881166	4.460139515
0.850004495	1.285993787	1.699995068	4.721212919
0.900032976	1.377404797		

Curve

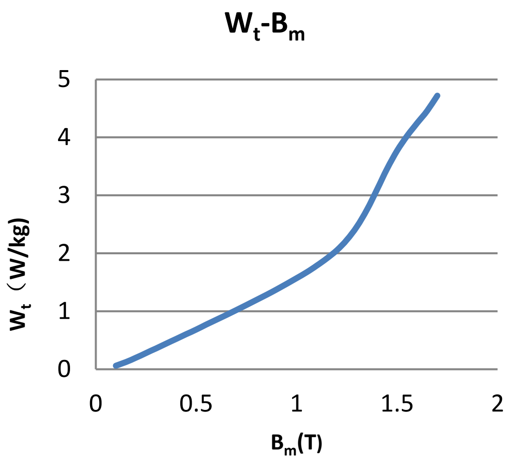


Fig. A2.32 W_t-B_m curve of silicon steel with 10A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100002176	0.061223303	0.949997284	1.47407585	
0.150066186	0.123634941	1.000024537	1.574018024	
0.200000758	0.198358788	1.04991722	1.678145847	
0.249989615	0.278554174	1.099960696	1.791103577	
0.300002792	0.360056909	1.149996956	1.917196212	
0.349983479	0.441109871	1.199919968	2.062477834	
0.400017887	0.522627393	1.249970976	2.23972374	
0.450006845	0.604130807	1.300694762	2.469344228	
0.499996876	0.68594294	1.34977854	2.756474405	
0.549969508	0.769980382	1.399823841	3.104883976	
0.600009007	0.853809642	1.449923358	3.459544328	
0.649982998	0.938266071	1.499859	3.772074693	
0.699968401	1.023315323	1.549952628	4.031223311	
0.750016895	1.109839974	1.599995146	4.248533148	
0.799982667	1.197981926	1.649752808	4.45719621	
0.850011687	1.288027579	1.699225774	4.706861052	
0.899991265	1.379201848			

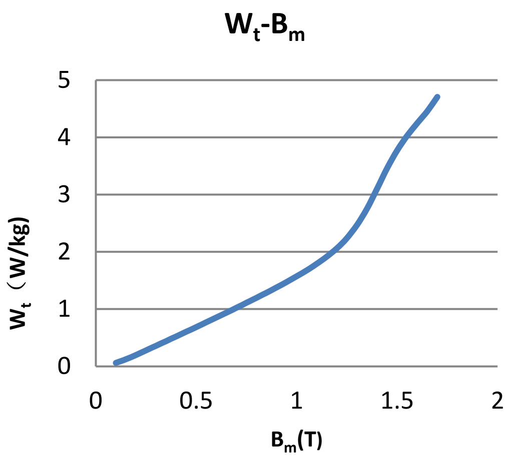


Fig. A2.33 W_t-B_m curve of silicon steel with 15A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.09999964	0.061352259	0.950031616	1.47533545	
0.149994013	0.124163474	1.000064783	1.575650899	
0.200019379	0.198399173	1.049989181	1.681082875	
0.249996149	0.277945489	1.100061498	1.796518288	
0.300011304	0.359377804	1.150007563	1.924309934	
0.349987831	0.44020102	1.200037561	2.072066542	
0.399998164	0.521501196	1.249977846	2.248558294	
0.450015144	0.602521319	1.300039526	2.474197022	
0.499998651	0.683635997	1.349964583	2.762788227	
0.549996122	0.768751643	1.400068897	3.108295175	
0.600005971	0.852332143	1.449999959	3.457710455	
0.650006884	0.936463209	1.499827875	3.764092104	
0.699995757	1.021902758	1.549933067	4.016910246	
0.750015982	1.108833763	1.599999423	4.223220058	
0.799981307	1.196709591	1.650019948	4.411675097	
0.84998604	1.286784413	1.699774189	4.604800068	
0.899991844	1.379334057			

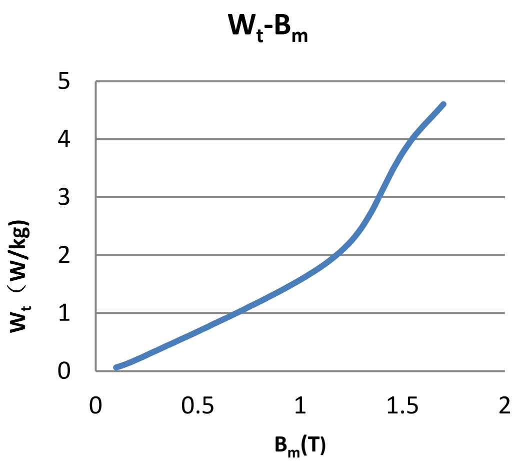


Fig. A2.34 W_t-B_m curve of silicon steel with 20A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100001151	0.061383276	0.949998213	1.476402442	
0.150016915	0.124013795	1.000006272	1.576492992	
0.200003549	0.198297781	1.049996712	1.684132518	
0.250005074	0.277710087	1.100039689	1.80011911	
0.300003668	0.358688463	1.149994963	1.930655094	
0.350017873	0.439975052	1.200000515	2.078572694	
0.399999834	0.521035851	1.250026257	2.254197618	
0.450011552	0.601971049	1.300011266	2.477298083	
0.500008157	0.6832487	1.350039032	2.763378114	
0.549929472	0.767601927	1.399737826	3.10379846	
0.600006881	0.851483957	1.45001745	3.455995436	
0.649991784	0.936245701	1.49983687	3.762658916	
0.70001903	1.020757145	1.550014737	4.015945429	
0.749952531	1.107092506	1.599965942	4.221824395	
0.799978384	1.195863966	1.650044506	4.410645286	
0.850047232	1.286256547	1.700058891	4.600714472	
0.900004324	1.379878161			

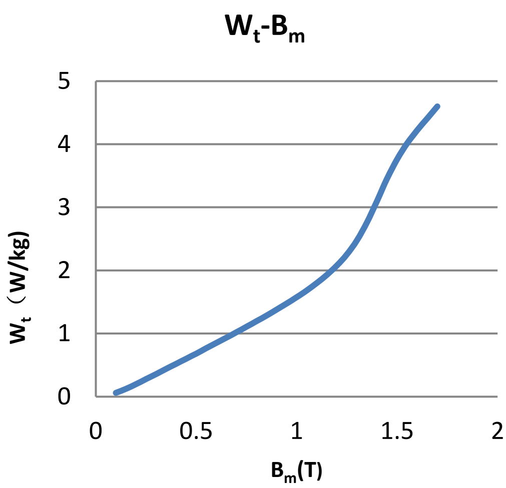


Fig. A2.35 W_t-B_m curve of silicon steel with 25A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100005547	0.06143386	0.95001864	1.477751734	
0.150002752	0.124044898	0.999992669	1.579155551	
0.199996644	0.19759531	1.050012918	1.687677075	
0.250012798	0.277186394	1.100000924	1.805913576	
0.300005028	0.358330682	1.149987577	1.938769588	
0.350008819	0.439344537	1.199985256	2.087088962	
0.399998552	0.520724757	1.250007375	2.261425371	
0.449995114	0.601784859	1.300007139	2.482260734	
0.500012217	0.685280435	1.349939886	2.76311837	
0.550015768	0.76804582	1.400025384	3.106116827	
0.600016369	0.851971846	1.449965335	3.455670018	
0.649932307	0.936030006	1.49999257	3.764841082	
0.699998284	1.021556606	1.549819558	4.015484654	
0.750005873	1.108839511	1.599994569	4.223896759	
0.800010948	1.197107229	1.649895016	4.409625083	
0.849981823	1.287654927	1.699872135	4.605276347	
0.899986273	1.380262015			

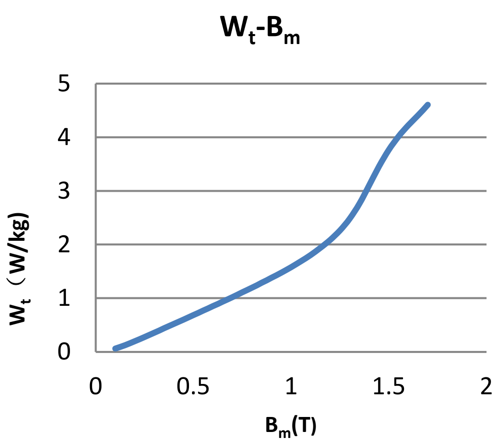


Fig. A2.36 W_t-B_m curve of silicon steel with 30A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100002045	0.061626746	0.950014465	1.479468258	
0.150007127	0.124149625	0.999957284	1.582288375	
0.200010174	0.198011807	1.049981221	1.692724058	
0.250003332	0.276952837	1.100023269	1.814024652	
0.300006042	0.35772244	1.149966187	1.947476657	
0.350012337	0.438933145	1.200027448	2.097022526	
0.399999412	0.519991715	1.250025521	2.269213702	
0.449986269	0.601015149	1.299901703	2.48605773	
0.499967718	0.684703663	1.349992176	2.76389236	
0.54999635	0.767776564	1.399889871	3.10420139	
0.599998071	0.851302646	1.449981541	3.455173759	
0.650002358	0.935683482	1.499837098	3.762777014	
0.700005274	1.021188722	1.550040437	4.016438235	
0.750036556	1.107923658	1.599777687	4.222972774	
0.800031866	1.1970264	1.649941848	4.410126253	
0.849996475	1.287684642	1.699742827	4.60334775	
0.899985371	1.381208379			

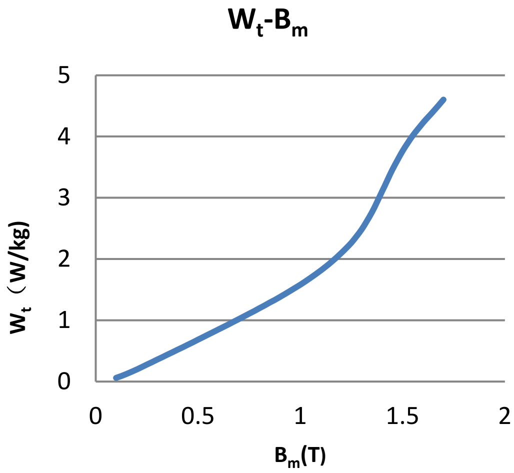


Fig. A2.37 W_t-B_m curve of silicon steel with 35A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100001784	0.061767185	0.950040378	1.481104517	
0.150014759	0.124204954	0.999994076	1.585646907	
0.200007279	0.197764867	1.049993646	1.698700027	
0.249993064	0.276421854	1.099966193	1.822926738	
0.299990854	0.356921476	1.150008732	1.958956524	
0.350019591	0.438132273	1.199987308	2.107920574	
0.399993523	0.519217985	1.250023893	2.288627257	
0.450011754	0.600547297	1.300000923	2.494008059	
0.49997905	0.68424587	1.350029638	2.766524249	
0.550016382	0.767108284	1.399991563	3.106083342	
0.599985478	0.850801565	1.44984276	3.454625137	
0.650024825	0.935404808	1.499779872	3.762267625	
0.700015107	1.020932849	1.549887235	4.014956304	
0.75001968	1.108052046	1.59988313	4.222407906	
0.799981507	1.196881491	1.649663714	4.409485656	
0.850010183	1.288622591	1.699635836	4.603091647	
0.900002259	1.382306994			

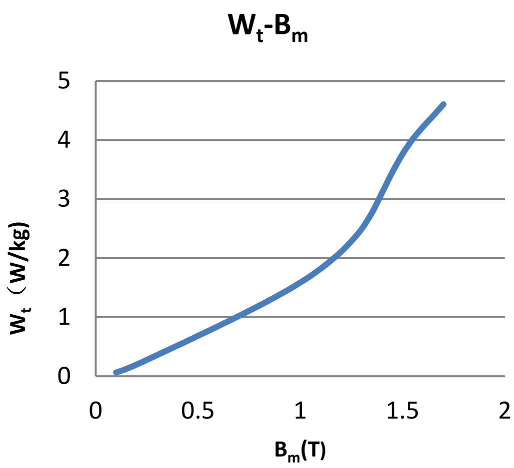


Fig. A2.38 W_t-B_m curve of silicon steel with 40A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.099995967	0.062021948	0.950023048	1.486915887
0.149998831	0.124556295	0.999956038	1.59306238
0.200001859	0.197948601	1.049991014	1.709149211
0.250005371	0.276344482	1.099996786	1.835826953
0.300000274	0.356811323	1.149966337	1.973768448
0.350019265	0.437984356	1.200003836	2.123369391
0.39999846	0.519191167	1.250016612	2.301699807
0.450025893	0.602251614	1.300011496	2.505004905
0.500034763	0.684780617	1.349943166	2.772015671
0.550011585	0.767659153	1.399959749	3.110786115
0.600033847	0.851433384	1.449974687	3.461020083
0.650051711	0.936113614	1.50002441	3.768998116
0.699996901	1.022024913	1.549881452	4.021006663
0.749970064	1.10916912	1.600015914	4.229301878
0.799967509	1.198624742	1.65009505	4.412571625
0.849955707	1.290894512	1.699642404	4.611395668
0.899953855	1.386594711		

Curve

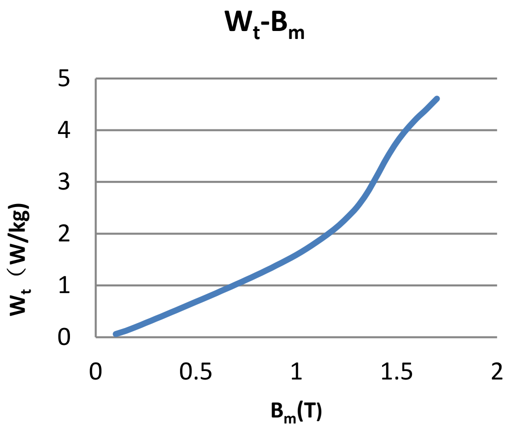


Fig. A2.39 W_t-B_m curve of silicon steel with 45A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.100002205	0.062134316	0.9499925	1.489728575
0.15001877	0.124472139	1.000010086	1.598165749
0.200008854	0.197404938	1.049990756	1.717422567
0.250009526	0.275404756	1.100017915	1.846702525
0.299993199	0.355700959	1.149993377	1.985051235
0.349999461	0.436482683	1.199951052	2.146734628
0.39997593	0.518626927	1.250049589	2.310692925
0.450047486	0.600845048	1.300065468	2.509190746
0.499976793	0.683347753	1.349998216	2.773165368
0.549976306	0.765872241	1.400011179	3.110408541
0.599998655	0.84998816	1.449910651	3.458120913
0.649975913	0.934856265	1.499829113	3.766710796
0.69998162	1.020888155	1.549842545	4.020960929
0.749956341	1.108121495	1.599747704	4.226484636
0.800018708	1.197713259	1.649805351	4.411723237
0.849971118	1.290604847	1.699749299	4.606253019
0.900036244	1.387304844		

Curve

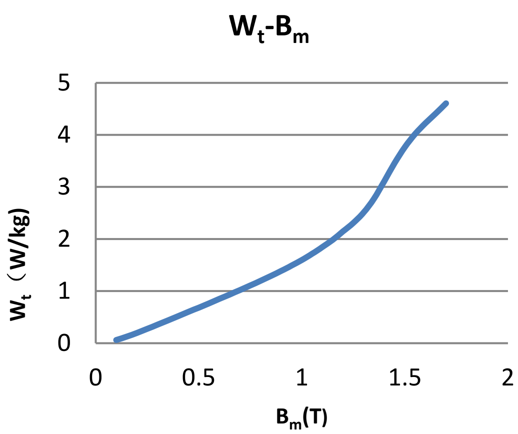


Fig. A2.40 W_t-B_m curve of silicon steel with 50A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.099996625	0.062377072	0.949829667	1.49607352
0.150067	0.12396032	0.999996243	1.610654114
0.20001948	0.196234745	1.050045267	1.735988918
0.249979225	0.273394986	1.100004692	1.868422567
0.300006624	0.353066042	1.149829113	2.007271373
0.349982821	0.433760554	1.200022897	2.166968878
0.400004079	0.516141631	1.250001588	2.328853639
0.450001125	0.598139463	1.299969936	2.518429184
0.500026408	0.679925504	1.349933558	2.774144433
0.550010625	0.762493332	1.399916917	3.108506358
0.599981186	0.846536644	1.4498076	3.456916056
0.64998249	0.931753652	1.499700373	3.764652641
0.699952887	1.017949832	1.549848542	4.019247702
0.750014795	1.106604838	1.599842081	4.22588606
0.800005116	1.196119675	1.649858036	4.412962385
0.850010726	1.291071551	1.699452398	4.605832824
0.90000724	1.390229045		

Curve

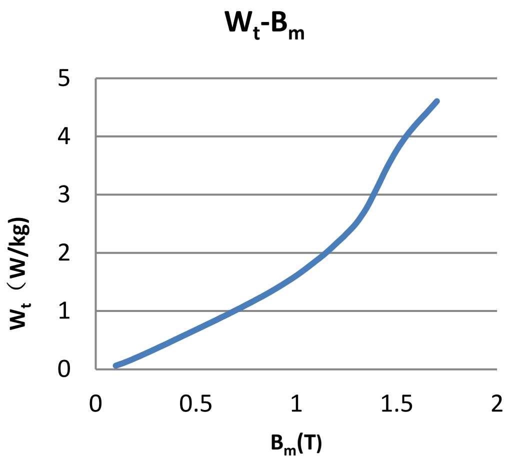


Fig. A2.41 W_t-B_m curve of silicon steel with 60A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.10000544	0.062683079	0.94999382	1.507724327
0.150019514	0.124195318	1.000031622	1.629285066
0.199990031	0.195197261	1.04996348	1.758377675
0.250020885	0.271135023	1.099978076	1.892976453
0.299988935	0.349907579	1.15000419	2.045725558
0.350022192	0.430104084	1.200051742	2.189626823
0.399997499	0.512548164	1.24997663	2.345065818
0.449994509	0.594451408	1.299937644	2.52996373
0.500021741	0.676775179	1.350016888	2.777831454
0.550038051	0.759828571	1.39989055	3.108027848
0.600001635	0.843684083	1.450132423	3.458355901
0.650001245	0.929084412	1.499731499	3.764156641
0.699996681	1.015936392	1.549764516	4.018861512
0.750009927	1.105347788	1.599640905	4.224518906
0.800029735	1.197727383	1.649967405	4.410286431
0.850022445	1.294364084	1.69943566	4.607468825
0.899982377	1.396846151		

Curve

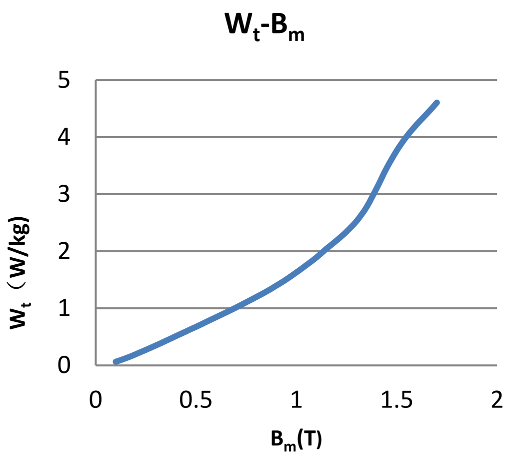


Fig. A2.42 W_t-B_m curve of silicon steel with 70A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.10000854	0.063124047	0.949984826	1.523425856
0.150015557	0.124203566	1.000036862	1.650366427
0.200003127	0.19420016	1.049964593	1.782092001
0.250005866	0.269005362	1.100037471	1.932893409
0.300002593	0.346248903	1.150058621	2.068935951
0.349990863	0.426203016	1.200005452	2.209101525
0.399983903	0.508581159	1.25001237	2.361062899
0.449988423	0.590331668	1.300037085	2.539808412
0.499991895	0.672643154	1.350021802	2.78190126
0.549989062	0.755663349	1.399660974	3.105832062
0.599999885	0.840063921	1.449864676	3.456188374
0.650000508	0.925910789	1.499798217	3.764281192
0.699997051	1.013977753	1.549788503	4.017302948
0.750025473	1.104894153	1.599662465	4.223703374
0.800011523	1.199146523	1.649604032	4.410457188
0.850018208	1.299033801	1.699429949	4.605957914
0.899982471	1.405961988		

Curve

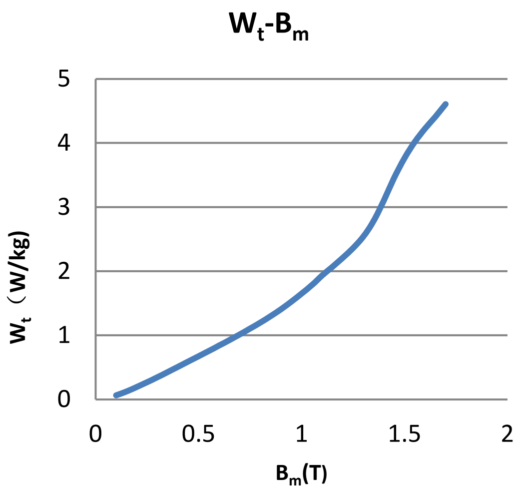


Fig. A2.43 W_t-B_m curve of silicon steel with 80A/m DC bias (in transverse direction, B27R090)

B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]
0.100005152	0.063451909	0.949970059	1.544209042
0.150009049	0.124047606	1.000042303	1.674885774
0.200007357	0.193013887	1.049991704	1.807847454
0.250002568	0.266660426	1.099996154	1.95466631
0.300001446	0.343447095	1.149999741	2.091186504
0.350000072	0.423064816	1.199997577	2.228793928
0.400030483	0.503996982	1.24997466	2.374020486
0.449989528	0.585534014	1.299968655	2.549959862
0.499996933	0.667885694	1.350030252	2.785404823
0.550003021	0.751248361	1.399932474	3.107370827
0.600012282	0.836094577	1.449883951	3.45447647
0.649920904	0.921763559	1.499711264	3.762973561
0.700017832	1.011665532	1.549605532	4.016405472
0.749983049	1.104450333	1.599776688	4.224690312
0.80001844	1.202425066	1.649705548	4.409815192
0.84997919	1.306518372	1.69981431	4.605100313
0.89998108	1.419397212		

Curve

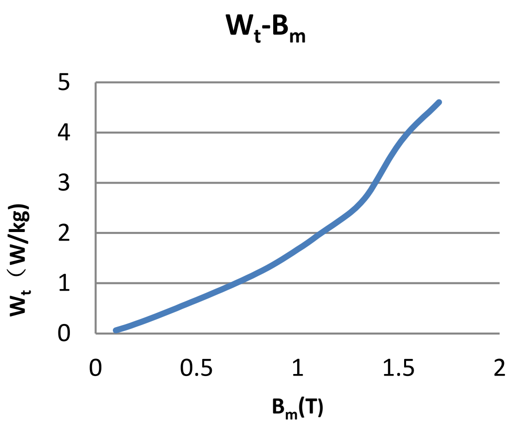


Fig. A2.44 W_t-B_m curve of silicon steel with 90A/m DC bias (in transverse direction, B27R090)

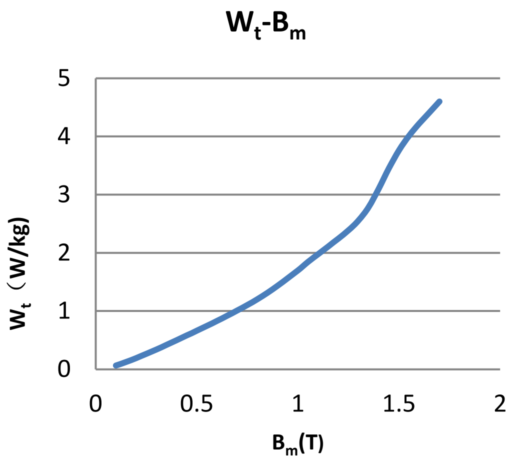
B_m[T]	W_t [W/kg]	B_m[T]	W_t [W/kg]	Curve
0.100003258	0.063752882	0.949963394	1.566726308	
0.14999842	0.123825499	1.000002224	1.699185325	
0.200008883	0.191848	1.050066391	1.846104437	
0.250016729	0.264263154	1.100031168	1.978106811	
0.300013122	0.339721374	1.149992663	2.111483886	
0.350005785	0.418973759	1.20007977	2.24579064	
0.399997032	0.499142758	1.249960781	2.38765484	
0.45001856	0.580322988	1.300037981	2.560022589	
0.499986497	0.662781823	1.349910482	2.788146821	
0.54997881	0.746329113	1.399934486	3.106675567	
0.600020403	0.830587594	1.449913328	3.45370333	
0.650006573	0.918621322	1.499841224	3.762214842	
0.70001916	1.00976897	1.549806779	4.017008338	
0.749940082	1.104155687	1.599809599	4.223476663	
0.799812216	1.205015522	1.649475103	4.410425109	
0.85002286	1.316108444	1.699421107	4.602306806	
0.899964536	1.437204853			

Fig. A2.45 W_t-B_m curve of silicon steel with 100A/m DC bias (in transverse direction, B27R090)

Fig.A2.46 shows the comparison of the W_t-B_m curves with different DC-biases in transverse directions.

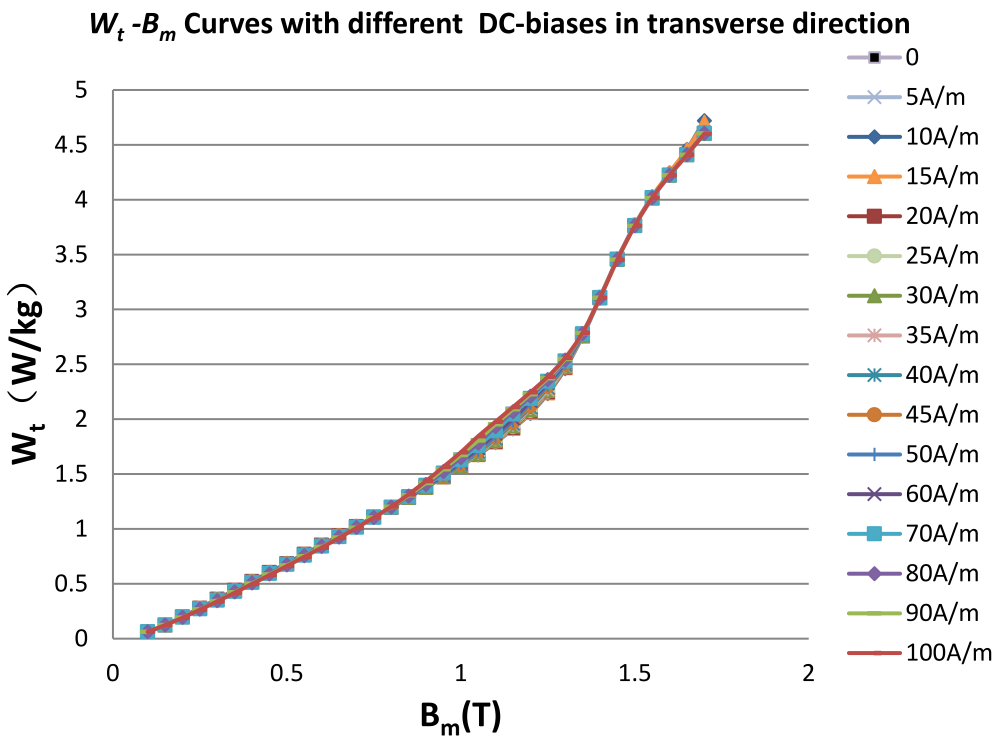


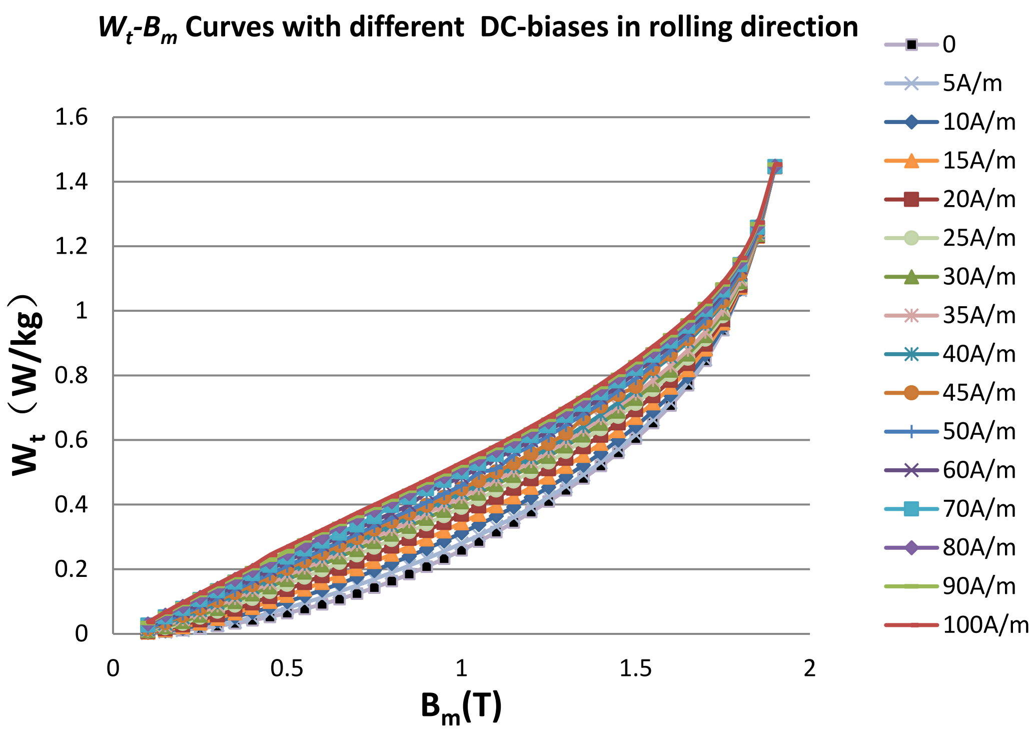
Fig. A2.46 W_t-B_m curves of silicon steel with different DC-biases (in transverse direction, B27R090)

2.5 Simplification of multiple measured specific total loss curves(B27R090)

In order to simplify the calculation of the iron loss inside the laminated sheets under complex AC-DC hybrid excitation, the average specific total loss curve is proposed, which represents the average specific total loss in a certain DC-bias (i.e.,H_{dc}) range.

As an example, herein 16 W_t- B_m curves with different degrees of DC bias(H_{dc}) measured in the rolling direction (see below) are treated as three average specific total loss curves, i.e., 0-25A/m, 26-50 A/m and 51-100 A/m. See Fig.A2.47 and Table A2.01.

Note that the determination of the average specific total loss curves should take account of the actual H_{dc} distribution in the solved field region.



W_t-B_m curves of silicon steel with different DC-biases (in rolling direction, B27R090)

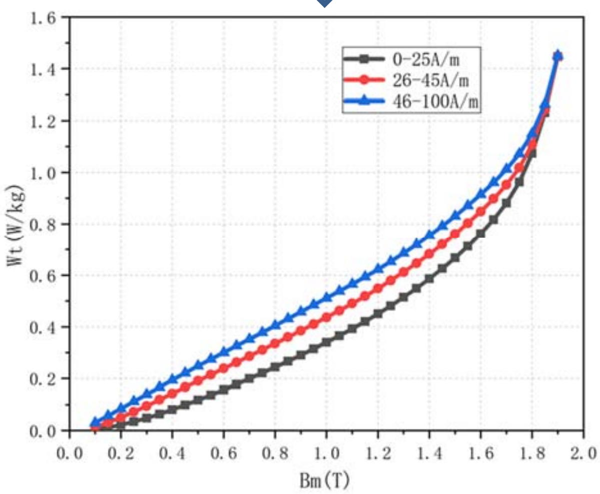


Fig. A2.47 Average specific total loss curves (in rolling direction)

Table A2.01 Average specific total loss curves (in rolling direction)

Average specific total loss curves with different H_{dc}(A/m)					
5-25A/m		30-45A/m		50-100A/m	
B_m(T)	W_t(W/kg)	B_m(T)	W_t(W/kg)	B_m(T)	W_t(W/kg)
0.1	0.005552	0.1	0.014121	0.1	0.030206
0.15	0.012328	0.15	0.030729	0.15	0.057268
0.2	0.022317	0.2	0.050708	0.2	0.084543
0.25	0.034604	0.25	0.072267	0.25	0.112243
0.3	0.048609	0.3	0.095136	0.3	0.139719
0.35	0.06406	0.35	0.118856	0.35	0.166955
0.4	0.080809	0.4	0.142896	0.4	0.194112
0.45	0.098696	0.45	0.166911	0.45	0.221165
0.5	0.117525	0.5	0.190794	0.5	0.247926
0.55	0.137098	0.55	0.214585	0.55	0.274247
0.6	0.157274	0.6	0.238374	0.6	0.300162
0.65	0.177986	0.65	0.262247	0.65	0.325885
0.7	0.199242	0.7	0.286267	0.7	0.351692
0.75	0.221078	0.75	0.310489	0.75	0.377786
0.8	0.243525	0.8	0.33496	0.8	0.404214
0.85	0.266591	0.85	0.35972	0.85	0.430873
0.9	0.290266	0.9	0.38481	0.9	0.457601
0.95	0.314562	0.95	0.410282	0.95	0.484281
1	0.339541	1	0.436224	1	0.510935
1.05	0.365345	1.05	0.462779	1.05	0.537749
1.1	0.392181	1.1	0.490147	1.1	0.565035
1.15	0.420292	1.15	0.518562	1.15	0.593158
1.2	0.449909	1.2	0.548248	1.2	0.62244
1.25	0.481209	1.25	0.579373	1.25	0.653115
1.3	0.514311	1.3	0.612037	1.3	0.685313
1.35	0.549309	1.35	0.646307	1.35	0.719099
1.4	0.58633	1.4	0.682281	1.4	0.754523
1.45	0.625598	1.45	0.720164	1.45	0.791663
1.5	0.667474	1.5	0.760272	1.5	0.830633
1.55	0.712509	1.55	0.802965	1.55	0.871606
1.6	0.761622	1.6	0.848596	1.6	0.914898
1.65	0.816602	1.65	0.897771	1.65	0.961247
1.7	0.881193	1.7	0.952419	1.7	1.012441
1.75	0.962787	1.75	1.018135	1.75	1.072566
1.8	1.074003	1.8	1.10759	1.8	1.150359

1.85	1.231606	1.85	1.242625	1.85	1.263893
1.9	1.446504	1.9	1.447678	1.9	1.450376

For the same reason, considering that there is little difference among the measured 16 specific total loss curves (in the transverse direction, see below), it is treated as one average specific total loss curve. See Fig. A2.48 and Table A2.02.

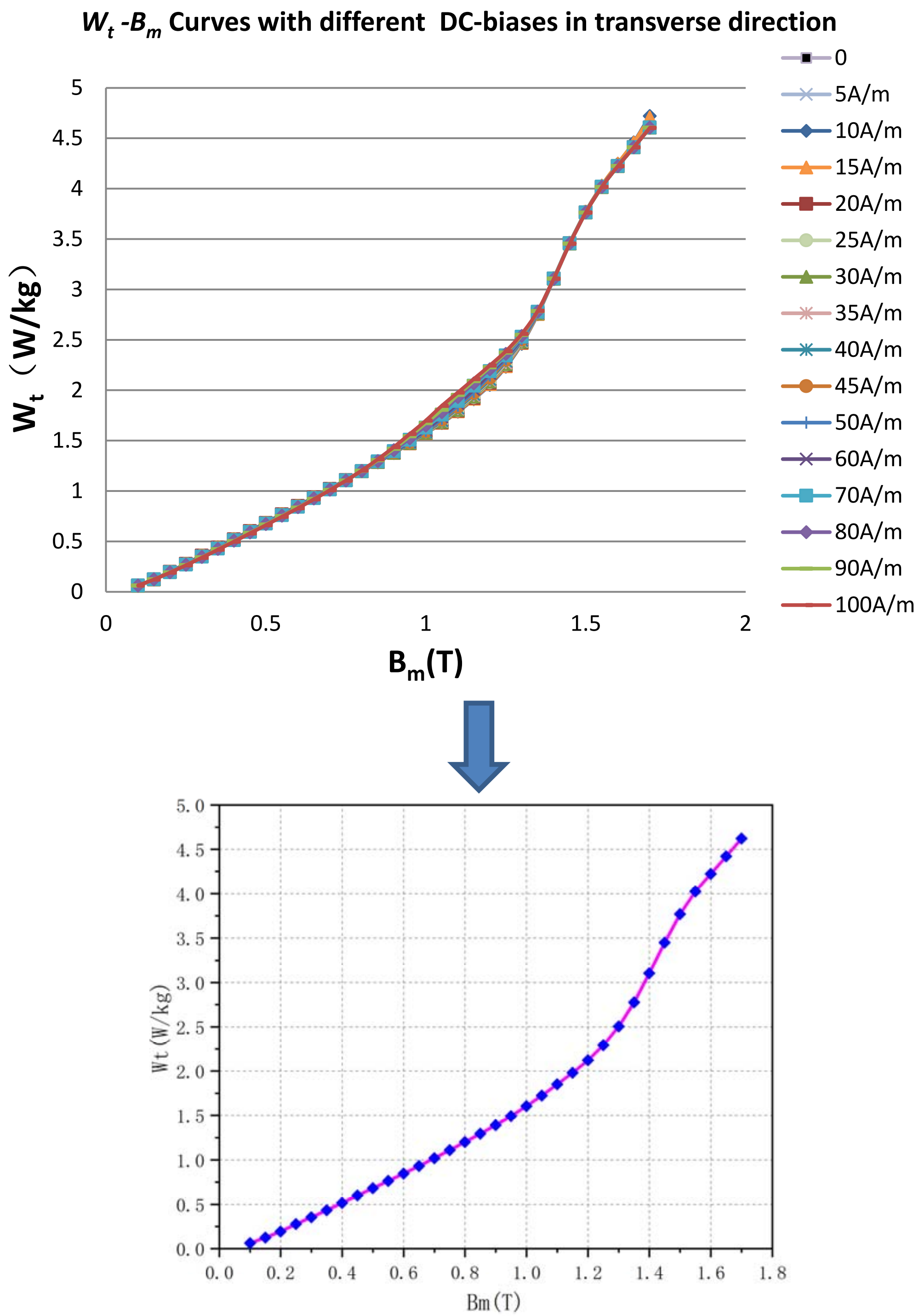


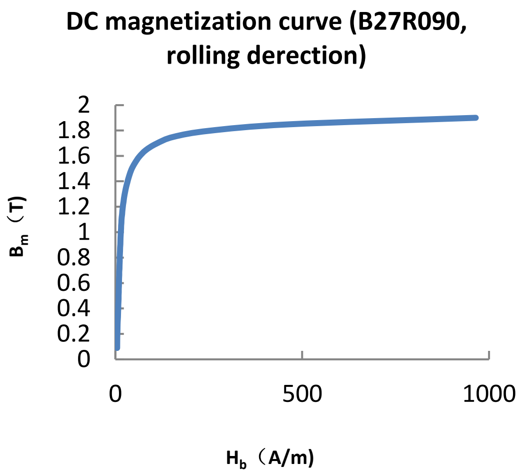
Fig. A2.48 Average specific total loss curves (in transverse direction, B27R090)

Table A2.02 Average specific total loss curves (in transverse direction, B27R090)

B_m(T)	W_t(W/kg)	B_m(T)	W_t(W/kg)
0.1	0.061918	0.95	1.491917
0.15	0.125051	1	1.604428
0.2	0.194351	1.05	1.725351
0.25	0.276826	1.1	1.851669
0.3	0.355565	1.15	1.982501
0.35	0.43332	1.2	2.124027
0.4	0.514996	1.25	2.291486
0.45	0.599435	1.3	2.504841
0.5	0.683019	1.35	2.777676
0.55	0.764591	1.4	3.103791
0.6	0.846233	1.45	3.45064
0.65	0.93071	1.5	3.769377
0.7	1.018908	1.55	4.023843
0.75	1.10951	1.6	4.223221
0.8	1.200839	1.65	4.419734
0.85	1.293055	1.7	4.620948
0.9	1.388842		

2.6 DC magnetization *B-H* curves(B27R090)

The measured DC magnetization *B-H* curves in both rolling and transverse directions are shown Figs.A2.49-50.

B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]	Curve
0.089672314	4.444272118	1.095230836	16.27725112	
0.23138066	5.185415603	1.141906755	17.64424322	
0.289827353	5.906920769	1.1942906	19.39210516	
0.334217026	6.516273485	1.240329654	21.47325227	
0.37896013	7.148888025	1.292358703	24.13948836	
0.424871859	7.692349698	1.338210014	27.37435774	
0.475446169	8.272194167	1.388978669	31.50437852	
0.528304115	8.683409756	1.442589839	36.63668195	
0.577795178	9.17866735	1.495451176	43.11979863	
0.638823378	9.795061882	1.542157069	51.72828822	
0.68806458	10.27015658	1.594534463	63.77963924	
0.741224704	10.99114195	1.645168369	81.07844095	
0.80117752	11.44630494	1.696213669	108.9149343	
0.852248324	12.16058491	1.750655415	155.4616351	
0.905322181	12.86864197	1.798539024	250.9359366	
0.955282898	13.59036378	1.848932075	462.3698846	

1.000761689	14.29602344	1.900086662	964.3478823	
1.052642966	15.34223899			

Fig.A2.49 DC magnetization *B-H* curve of silicon steel (in rolling direction, B27R090)

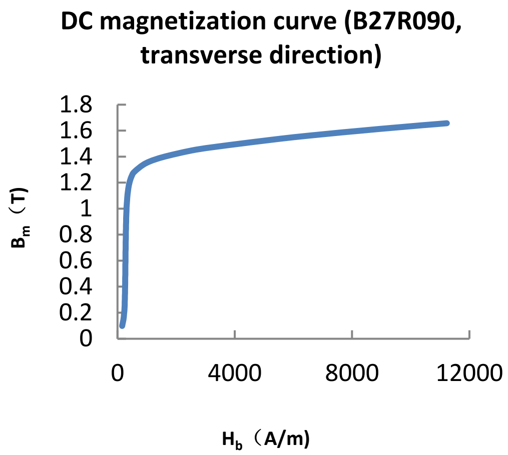
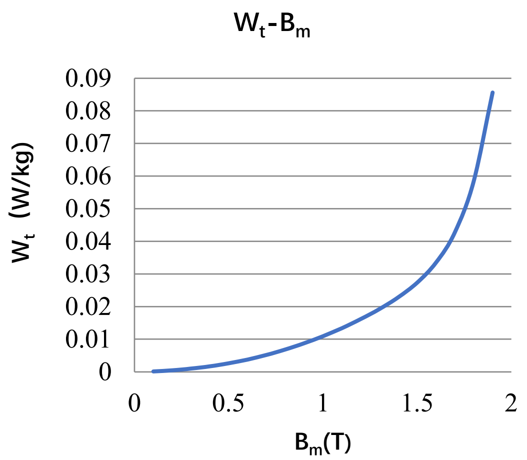
B_m[T]	H_b [A/m]	B_m[T]	H_b [A/m]	Curve
0.097368237	154.1994435	0.926641716	294.3144131	
0.145608989	198.6409442	0.981684124	302.6779353	
0.192293012	223.5414791	1.035455585	314.1235369	
0.236815599	237.4562073	1.086259009	330.2955568	
0.281685947	245.2669495	1.141893947	357.2976602	
0.328292861	250.6151917	1.19553356	399.9408069	
0.373546033	254.5839422	1.246659578	475.3929184	
0.42581341	258.3092216	1.282580513	569.8013635	
0.468644962	261.423365	1.351088172	974.8294047	
0.516750409	264.5680758	1.400721917	1618.99681	
0.568740461	267.3583747	1.453583445	2682.091403	
0.610742193	270.187364	1.500033837	4163.47957	
0.665002711	273.1501662	1.549585051	6025.67038	
0.717334688	276.3077025	1.599628214	8267.030184	
0.770914147	279.8764037	1.65031179	10842.32359	
0.821544846	283.7236324	1.657231248	11230.1513	
0.874320472	288.2960375			

Fig.A2.50 DC magnetization *B-H* curve of silicon steel (in transverse direction, B27R090)

2.7 Magnetic Properties at low frequency (5Hz, B27R090)

The magnetic properties of GO silicon steel (B27R090) at low frequency(5Hz) have been measured by using SST(Brockhaus) to possibly extend the model to include the effect of very low frequency on magnetization and loss behaviors.

B_m[T]	W_t [W/kg]	Curve
0.099996474	0.000141217	
0.199980888	0.000485525	
0.299998007	0.001002815	
0.399953039	0.001705765	
0.499953481	0.002628576	
0.599992859	0.003789661	
0.699930678	0.005192055	
0.799965605	0.006854795	
0.89983523	0.00876326	
0.99993646	0.010935987	
1.100041474	0.013398878	
1.200044793	0.016155616	
1.299992785	0.019274189	
1.400027088	0.022884347	
1.500059807	0.027375727	
1.600061282	0.033479323	
1.700029621	0.042746462	

1.80002034	0.058456408	
1.900223229	0.085625767	

Fig.A2.51 W_t-B_m curve of silicon steel at low frequency(5Hz, in rolling direction, B27R090)

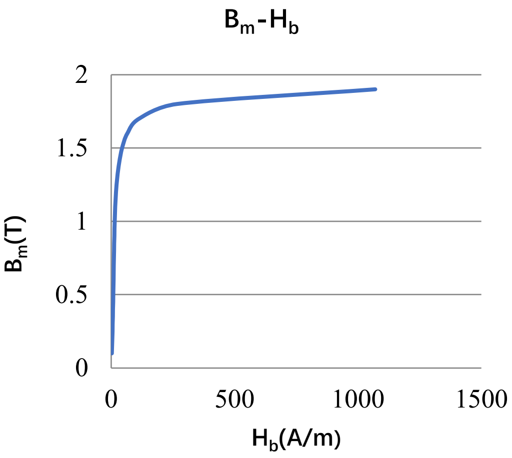
B_m[T]	H_b [A/m]	Curve
0.099996474	2.936322835	
0.199980888	4.755115289	
0.299998007	6.25677002	
0.399953039	7.521045736	
0.499953481	8.609531657	
0.599992859	9.616602241	
0.699930678	10.5946818	
0.799965605	11.57329576	
0.89983523	12.75952284	
0.99993646	14.25423041	
1.100041474	16.42120904	
1.200044793	19.69679362	
1.299992785	24.70863308	
1.400027088	32.28023275	
1.500059807	44.25018446	
1.600061282	65.52665473	
1.700029621	113.0262383	
1.80002034	266.2444526	
1.900223229	1069.795397	

Fig.A2.52 B_m-H_b curve of silicon steel (in rolling direction, B27R090)

3 Measured Exciting Current Waveforms(P21^e)

The measured exciting current waveforms and corresponding sampled point data under different excitation conditions are sorted out to be used in modeling and simulation of stray magnetic field loss inside models' load-components(P21^e-EM(NS) and P21^e-M(NS)) and magnetic flux densities at specified positions of the models.

Note that all the hybrid excitation cases applied in the upgraded models of the new member-set of Problem 21 Family (P21^e-EM(NS) and P21^e-M(NS)) have been specified in the benchmarking report. Table A3.0 below shows the hybrid excitation cases in more detail.

Table A3.0
AC-DC Hybrid Excitation Cases(in Model-based Measurement)

Cases	Excitation conditions	Remarks
I	$U_1 \sin(\omega t+0)$	In each case, the excitation current (AC) reaches 10A (rms), but without DC bias.
II	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$	
III	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$ $+U_5 \sin(5\omega t+0)+U_7 \sin(7\omega t+0)$	
IV (ADH1)	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$ *(with DC biases)*	Hybrid excitation at the same side of model's load-component, AC reaches 7A (rms), and includes DC (5A).
V (ADH2)	$U_1 \sin(\omega t+0)+U_3 \sin(3\omega t+0)$ *(with DC biases)*	Hybrid excitation at the two side of model's load-component, AC reaches 7A (rms) at one side, and DC reaches 5A at another side.

Notes:
All phase angles of fundamental and harmonics are set to zero.
U_1 (fundamental, 50Hz, rms); U_3,U_5, and U_7 are of 30% U_1.

3.1 Measured Exciting Currents (Model P21^e-EM(NS))

The measured exciting current waveforms and the corresponding sampled points under different excitation conditions based on P21^e-EM(NS) are shown in Tables A3.1-A3.4 and Figs.A3.1-A3.4.

3.1.1 On the Exciting currents (Case I)

Case I (P21^e-EM(NS)): with copper plate and sinusoidal voltage source excitation.

3.1.2 Sampled Points and Waveform of Exciting currents (Case II)

Table A3.1 Sampled Points from Current Waveform (Case II: fundamental +3rd harmonic)

Time (ms)	Current(A)	Time (ms)	Current(A)	Time (ms)	Current(A)
0	0.3	13.5	11.2	27	-12.8
0.5	-1.26	14	12.9	27.5	-10.9
1	-2.79	14.5	14.3	28	-8.84
1.5	-4.38	15	15.2	28.5	-6.68
2	-6.1	15.5	15.5	29	-4.62
2.5	-7.92	16	15	29.5	-2.72
3	-9.81	16.5	13.9	30	-0.98
3.5	-11.7	17	12.3	30.5	0.6
4	-13.3	17.5	10.4	31	2.13
4.5	-14.6	18	8.25	31.5	3.69

5	-15.3	18.5	6.12	32	5.35
5.5	-15.5	19	4.07	32.5	7.12
6	-15.1	19.5	2.23	33	9.02
6.5	-14	20	0.55	33.5	10.9
7	-12.5	20.5	-1	34	12.6
7.5	-10.6	21	-2.54	34.5	14.1
8	-8.47	21.5	-4.12	35	15.1
8.5	-6.35	22	-5.8	35.5	15.5
9	-4.31	22.5	-7.63	36	15.1
9.5	-2.42	23	-9.52	36.5	14.1
10	-0.73	23.5	-11.4	37	12.6
10.5	0.85	24	-13.1	37.5	10.7
11	2.39	24.5	-14.4	38	8.58
11.5	3.94	25	-15.2	38.5	6.45
12	5.61	25.5	-15.5	39	4.41
12.5	7.41	26	-15.2	39.5	2.51
13	9.31	26.5	-14.3	40	0.8

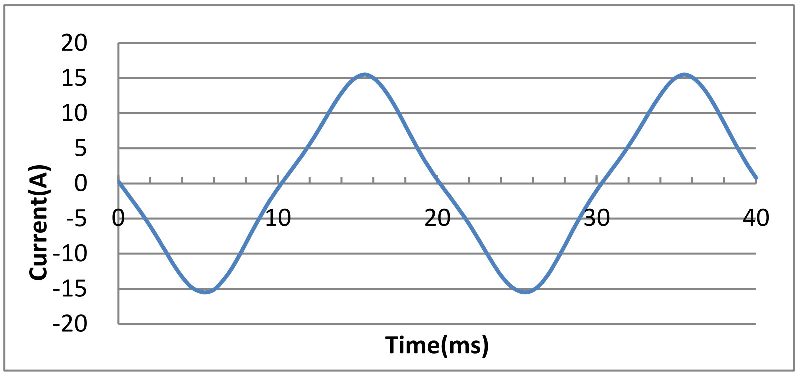


Fig.A3.1 Measured current waveform (Case II : fundamental + 3rd harmonic)

3.1.3 Sampled Points and Waveform of Exciting currents (Case III)

Table A3.2 Sampled Points from Current Waveform
(Case III: fundamental + (3rd + 5th +7th) harmonics)

Time (ms)	Current(A)	Time (ms)	Current(A)	Time (ms)	Current(A)
0	12	13.5	-9.23	27	-2.74
0.5	14.1	14	-7.96	27.5	-4.6
1	16.1	14.5	-6.64	28	-6.64
1.5	16.8	15	-4.84	28.5	-8.4
2	15.4	15.5	-2.68	29	-9.57
2.5	13	16	-0.64	29.5	-10.5
3	10.6	16.5	1	30	-11.9
3.5	8.84	17	2.55	30.5	-14
4	7.63	17.5	4.39	31	-16
4.5	6.22	18	6.43	31.5	-16.9

5	4.26	18.5	8.23	32	-16.2
5.5	2.09	19	9.47	32.5	-14.1
6	0.18	19.5	10.4	33	-11.5
6.5	-1.42	20	11.7	33.5	-9.48
7	-3.01	20.5	13.8	34	-8.14
7.5	-4.92	21	15.8	34.5	-6.87
8	-6.94	21.5	16.9	35	-5.15
8.5	-8.62	22	15.8	35.5	-3.02
9	-9.72	22.5	13.4	36	-0.93
9.5	-10.7	23	10.9	36.5	0.77
10	-12.2	23.5	9.09	37	2.3
10.5	-14.3	24	7.82	37.5	4.06
11	-16.3	24.5	6.48	38	6.11
11.5	-16.9	25	4.62	38.5	7.98
12	-16	25.5	2.43	39	9.3
12.5	-13.7	26	0.45	39.5	10.3
13	-11.1	26.5	-1.17	40	11.5

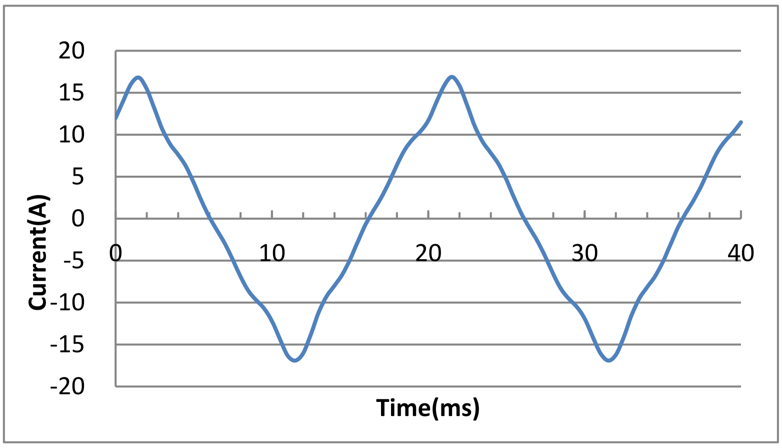


Fig. A3.2 Measured current waveform (Case III: fundamental +(3rd +5th + 7th) harmonics)

3.1.4 Sampled Points and Waveform of Exciting currents (Case IV)

Table A3.3 Sampled Points from Current Waveform (Case IV: fundamental + 3rd harmonic + DC; ADH1)

Time (ms)	**Current(A)**	**Time (ms)**	**Current(A)**	**Time (ms)**	**Current(A)**
0	-14	13.5	2.74	27	-4.04
0.5	-14.9	14	1.32	27.5	-2.94
1	-15.6	14.5	-0.15	28	-1.79
1.5	-15.8	15	-1.56	28.5	-0.52
2	-15.7	15.5	-2.88	29	0.8
2.5	-15.1	16	-4.07	29.5	2.17
3	-14.1	16.5	-5.17	30	3.45
3.5	-12.9	17	-6.24	30.5	4.57
4	-11.5	17.5	-7.35	31	5.38

4.5	-10	18	-8.53	31.5	5.8
5	-8.58	18.5	-9.81	32	5.71
5.5	-7.25	19	-11.2	32.5	5.15
6	-6.06	19.5	-12.5	33	4.21
6.5	-4.93	20	-13.8	33.5	2.97
7	-3.87	20.5	-14.8	34	1.55
7.5	-2.76	21	-15.5	34.5	0.09
8	-1.6	21.5	-15.8	35	-1.34
8.5	-0.32	22	-15.7	35.5	-2.68
9	1.01	22.5	-15.2	36	-3.88
9.5	2.38	23	-14.3	36.5	-5.01
10	3.65	23.5	-13.1	37	-6.07
10.5	4.72	24	-11.7	37.5	-7.17
11	5.48	24.5	-10.2	38	-8.34
11.5	5.82	25	-8.8	38.5	-9.61
12	5.65	25.5	-7.47	39	-10.9
12.5	5.03	26	-6.24	39.5	-12.3
13	4.02	26.5	-5.12	40	-13.6

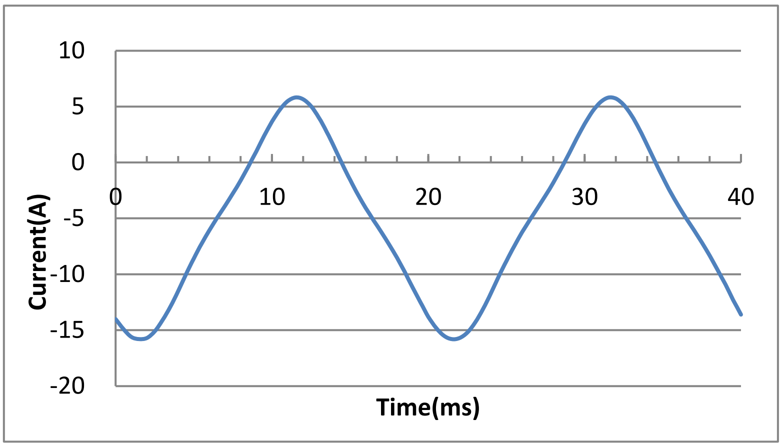


Fig.A3.3 Measured current waveform (Case IV: fundamental + 3rd harmonic +DC; one-side excitation: ADH1)

3.1.5 Sampled Points and Waveform of Exciting currents (Case V)

Table A3.4 Sampled Points from Current Waveform (Case V: fundamental + 3rd harmonic + DC; ADH2)

AC side(fundamental +3rd harmonic)				DC side			
Time	**Current(A)**	**Time**	**Current(A)**	**Time**	**Current(A)**	**Time**	**Current(A)**
0.0	9.20	20.5	8.16	0.0	-5.17	20.5	-5.17
0.5	7.95	21.0	6.76	0.5	-5.17	21.0	-5.17
1.0	6.50	21.5	5.26	1.0	-5.17	21.5	-5.17
1.5	5.02	22.0	3.77	1.5	-5.16	22.0	-5.16
2.0	3.54	22.5	2.40	2.0	-5.16	22.5	-5.15
2.5	2.19	23.0	1.14	2.5	-5.15	23.0	-5.13
3.0	0.95	23.5	0.00	3.0	-5.13	23.5	-5.12
3.5	-0.16	24.0	-1.08	3.5	-5.12	24.0	-5.11
4.0	-1.25	24.5	-2.15	4.0	-5.10	24.5	-5.09
4.5	-2.33	25.0	-3.29	4.5	-5.09	25.0	-5.07

5.0	-3.47	25.5	-4.50	5.0	-5.07	25.5	-5.05
5.5	-4.71	26.0	-5.79	5.5	-5.05	26.0	-5.02
6.0	-6.01	26.5	-7.12	6.0	-5.02	26.5	-5.00
6.5	-7.34	27.0	-8.40	6.5	-5.00	27.0	-4.97
7.0	-8.59	27.5	-9.51	7.0	-4.97	27.5	-4.94
7.5	-9.67	28.0	-10.30	7.5	-4.94	28.0	-4.91
8.0	-10.40	28.5	-10.80	8.0	-4.91	28.5	-4.89
8.5	-10.80	29.0	-10.70	8.5	-4.89	29.0	-4.87
9.0	-10.70	29.5	-10.20	9.0	-4.87	29.5	-4.85
9.5	-10.10	30.0	-9.26	9.5	-4.85	30.0	-4.85
10.0	-9.08	30.5	-8.02	10.0	-4.84	30.5	-4.84
10.5	-7.80	31.0	-6.59	10.5	-4.84	31.0	-4.84
11.0	-6.35	31.5	-5.10	11.0	-4.84	31.5	-4.84
11.5	-4.86	32.0	-3.62	11.5	-4.85	32.0	-4.85
12.0	-3.40	32.5	-2.26	12.0	-4.85	32.5	-4.86
12.5	-2.06	33.0	-1.02	12.5	-4.86	33.0	-4.87
13.0	-0.83	33.5	0.11	13.0	-4.87	33.5	-4.88
13.5	0.30	34.0	1.20	13.5	-4.89	34.0	-4.90
14.0	1.36	34.5	2.26	14.0	-4.90	34.5	-4.91
14.5	2.45	35.0	3.41	14.5	-4.92	35.0	-4.93
15.0	3.60	35.5	4.64	15.0	-4.94	35.5	-4.95
15.5	4.84	36.0	5.94	15.5	-4.96	36.0	-4.98
16.0	6.14	36.5	7.27	16.0	-4.98	36.5	-5.01
16.5	7.48	37.0	8.52	16.5	-5.01	37.0	-5.03
17.0	8.71	37.5	9.61	17.0	-5.04	37.5	-5.06
17.5	9.75	38.0	10.40	17.5	-5.07	38.0	-5.09
18.0	10.50	38.5	10.80	18.0	-5.09	38.5	-5.12
18.5	10.80	39.0	10.80	18.5	-5.12	39.0	-5.14
19.0	10.70	39.5	10.40	19.0	-5.14	39.5	-5.15
19.5	10.30	40.0	9.54	19.5	-5.16	40.0	-5.16
20.0	9.37			20.0	-5.17		

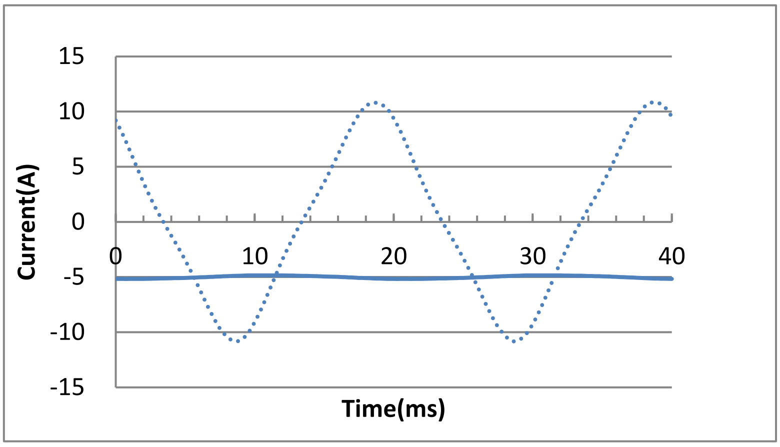


Fig.A3.4 Measured current waveform (Case V: fundamental + 3rd harmonic +DC; two-side excitation: ADH2)

It can be seen from Table A3.4 and Fig. A3.4 that the measured DC actually varies in a very small range, so it is not an accurate DC current. Therefore, the actual current waveform should be used in modeling and simulation.

3.2 Measured Exciting Currents (Model P21^{e}-M(NS))

The measured exciting current waveforms and the corresponding sampled points under different excitation conditions based on P21^{e}-M(NS) are shown in Tables A3.5-A3.9 and Figs.A3.5-A3.9.

3.2.1 Sampled Points and Waveform of Exciting currents (Case I)

Table A3.5 Sampled Points from Current Waveform (Case I: fundamental)

Time (s)	Current (A)	Time (s)	Current (A)	Time (s)	Current (A)	Time (s)	Current (A)
0	-11.60	10.00	11.20	20.00	-11.30	30.00	11.00
0.50	-12.70	10.50	12.40	20.50	-12.50	30.50	12.20
1.00	-13.50	11.00	13.30	21.00	-13.40	31.00	13.20
1.50	-14.00	11.50	13.90	21.50	-13.90	31.50	13.80
2.00	-14.10	12.00	14.10	22.00	-14.10	32.00	14.10
2.50	-14.00	12.50	14.00	22.50	-14.00	32.50	14.00
3.00	-13.50	13.00	13.50	23.00	-13.60	33.00	13.60
3.50	-12.70	13.50	12.60	23.50	-12.90	33.50	12.80
4.00	-11.60	14.00	11.50	24.00	-11.80	34.00	11.70
4.50	-10.20	14.50	10.10	24.50	-10.50	34.50	10.30
5.00	-8.60	15.00	8.41	25.00	-8.87	35.00	8.69
5.50	-6.73	15.50	6.53	25.50	-7.05	35.50	6.83
6.00	-4.72	16.00	4.50	26.00	-5.05	36.00	4.84
6.50	-2.57	16.50	2.35	26.50	-2.94	36.50	2.69
7.00	-0.39	17.00	0.16	27.00	-0.73	37.00	0.51
7.50	1.84	17.50	-2.06	27.50	1.49	37.50	-1.72
8.00	3.99	18.00	-4.21	28.00	3.66	38.00	-3.87
8.50	6.07	18.50	-6.28	28.50	5.76	38.50	-5.96
9.00	7.98	19.00	-8.18	29.00	7.69	39.00	-7.87
9.50	9.72	19.50	-9.88	29.50	9.46	39.50	-9.62
						40.00	-11.10

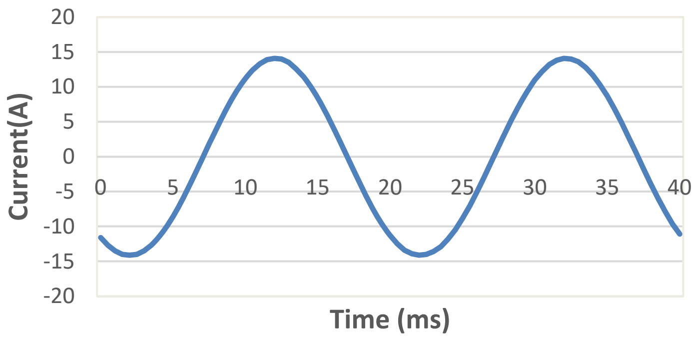


Fig.A3.5 Measured current waveform (Case I: fundamental)

3.2.2 Sampled Points and Waveform of Exciting currents (Case II)

Table A3.6 Sampled Points from Current Waveform (Case II: fundamental +3rd harmonic)

Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)
0.00	-15.40	10.00	15.40	20.00	-15.50	30.00	15.40
0.50	-14.90	10.50	14.70	20.50	-15.00	30.50	14.90
1.00	-13.70	11.00	13.50	21.00	-13.90	31.00	13.80
1.50	-12.10	11.50	11.90	21.50	-12.30	31.50	12.20
2.00	-10.10	12.00	9.88	22.00	-10.40	32.00	10.20
2.50	-8.01	12.50	7.78	22.50	-8.34	32.50	8.12
3.00	-5.90	13.00	5.68	23.00	-6.22	33.00	6.01
3.50	-3.93	13.50	3.71	23.50	-4.23	33.50	4.03
4.00	-2.11	14.00	1.93	24.00	-2.38	34.00	2.20
4.50	-0.47	14.50	0.28	24.50	-0.72	34.50	0.55
5.00	1.09	15.00	-1.25	25.00	0.85	35.00	-1.02
5.50	2.64	15.50	-2.81	25.50	2.37	35.50	-2.56
6.00	4.24	16.00	-4.41	26.00	3.98	36.00	-4.16
6.50	5.98	16.50	-6.18	26.50	5.68	36.50	-5.89
7.00	7.84	17.00	-8.04	27.00	7.53	37.00	-7.74
7.50	9.76	17.50	-9.97	27.50	9.46	37.50	-9.67
8.00	11.60	18.00	-11.80	28.00	11.30	38.00	-11.50
8.50	13.30	18.50	-13.40	28.50	13.10	38.50	-13.20
9.00	14.60	19.00	-14.70	29.00	14.40	39.00	-14.50
9.50	15.30	19.50	-15.40	29.50	15.20	39.50	-15.30
						40.00	-15.50

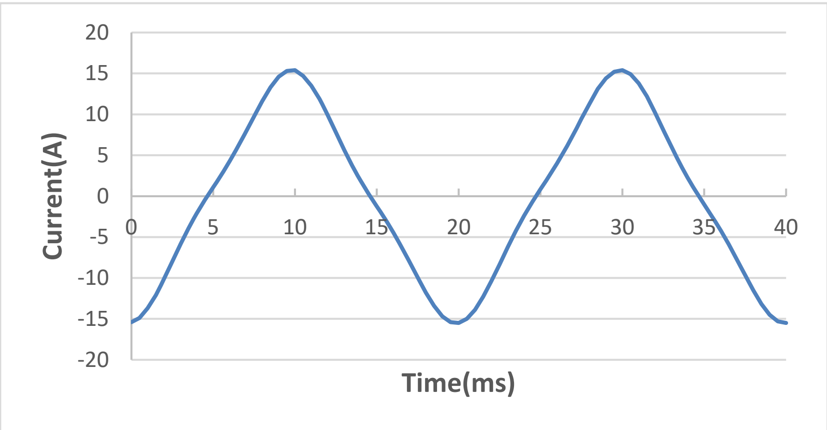


Fig.A3.6 Measured Current waveform (Case II : fundamental + 3rd harmonic)

3.2.3 Sampled Points and Waveform of Exciting currents (Case III)

Table A3.7 Sampled Points from Current Waveform (Case III: fundamental + (3^{rd} + 5^{th} +7^{th}) harmonics)

Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)
0.00	3.98	10.00	-4.19	20.00	3.65	30.00	-3.88
0.50	6.03	10.50	-6.25	20.50	5.70	30.50	-5.92
1.00	7.91	11.00	-8.07	21.00	7.63	31.00	-7.82
1.50	9.20	11.50	-9.31	21.50	9.04	31.50	-9.15
2.00	10.20	12.00	-10.30	22.00	10.00	32.00	-10.10
2.50	11.50	12.50	-11.70	22.50	11.20	32.50	-11.40
3.00	13.50	13.00	-13.70	23.00	13.10	33.00	-13.40
3.50	15.70	13.50	-15.90	23.50	15.30	33.50	-15.60
4.00	16.90	14.00	-16.90	24.00	16.80	34.00	-16.80
4.50	16.00	14.50	-16.40	24.50	16.20	34.50	-16.60
5.00	13.70	15.00	-14.40	25.00	14.10	35.00	-14.80
5.50	11.20	15.50	-11.90	25.50	11.60	35.50	-12.30
6.00	9.37	16.00	-9.79	26.00	9.62	36.00	-10.10
6.50	8.12	16.50	-8.42	26.50	8.30	36.50	-8.62
7.00	6.85	17.00	-7.22	27.00	7.08	37.00	-7.43
7.50	5.04	17.50	-5.56	27.50	5.35	37.50	-5.88
8.00	2.86	18.00	-3.46	28.00	3.23	38.00	-3.81
8.50	0.86	18.50	-1.36	28.50	1.15	38.50	-1.67
9.00	-0.80	19.00	0.37	29.00	-0.54	39.00	0.13
9.50	-2.34	19.50	1.92	29.50	-2.08	39.50	1.67
						40.00	3.35

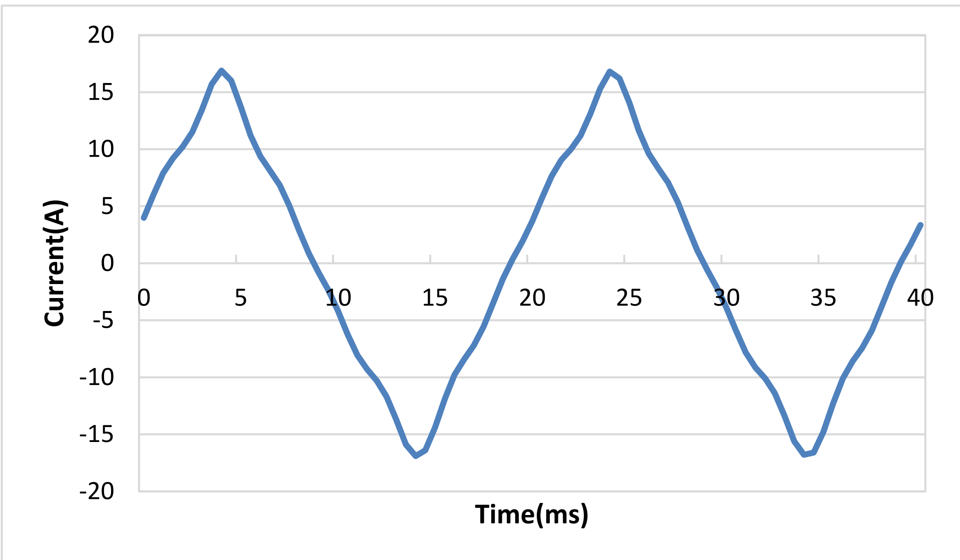


Fig.A3.7 Measured Current waveform (Case III: fundamental +(3^{rd} +5^{th} + 7^{th}) harmonics)

3.2.4 Sampled Points and Waveform of Exciting currents (Case IV)

Table A3.8 Sampled Points from Current Waveform (Case IV: fundamental + 3rd harmonic + DC; ADH1)

Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)
0.00	-15.60	10.00	5.55	20.00	-15.70	30.00	5.62
0.50	-15.00	10.50	4.85	20.50	-15.10	30.50	4.98
1.00	-13.90	11.00	3.79	21.00	-14.10	31.00	3.98
1.50	-12.70	11.50	2.50	21.50	-12.90	31.50	2.72
2.00	-11.20	12.00	1.07	22.00	-11.50	32.00	1.29
2.50	-9.80	12.50	-0.37	22.50	-10.00	32.50	-0.14
3.00	-8.40	13.00	-1.76	23.00	-8.61	33.00	-1.55
3.50	-7.12	13.50	-3.04	23.50	-7.32	33.50	-2.83
4.00	-5.94	14.00	-4.19	24.00	-6.13	34.00	-4.02
4.50	-4.86	14.50	-5.29	24.50	-5.03	34.50	-5.11
5.00	-3.77	15.00	-6.36	25.00	-3.95	35.00	-6.19
5.50	-2.64	15.50	-7.50	25.50	-2.84	35.50	-7.31
6.00	-1.44	16.00	-8.71	26.00	-1.64	36.00	-8.51
6.50	-0.13	16.50	-10.00	26.50	-0.36	36.50	-9.82
7.00	1.24	17.00	-11.40	27.00	1.02	37.00	-11.20
7.50	2.61	17.50	-12.80	27.50	2.40	37.50	-12.60
8.00	3.87	18.00	-14.00	28.00	3.67	38.00	-13.80
8.50	4.88	18.50	-15.00	28.50	4.74	38.50	-14.90
9.00	5.56	19.00	-15.60	29.00	5.49	39.00	-15.60
9.50	5.82	19.50	-15.90	29.50	5.81	39.50	-15.80
						40.00	-15.70

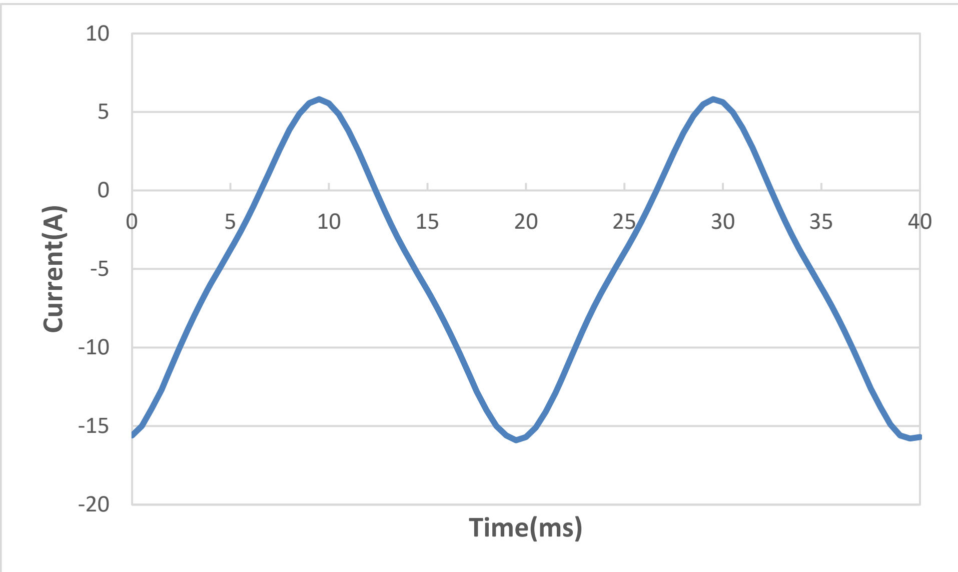


Fig. A3.8 Measured current waveform (Case IV: fundamental + 3rd harmonic +DC; one-side excitation: ADH1)

3.2.5 Sampled Points and Curve of Exciting currents (Case V)

Table A3.9 Sampled Points from Current waveform (Case V: fundamental + 3rd harmonic + DC; ADH2)

Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)	Time (ms)	Current (A)
0.00	10.70	10.00	-10.70	20.00	10.70	30.00	-10.70
0.50	10.80	10.50	-10.80	20.50	10.80	30.50	-10.80
1.00	10.30	11.00	-10.50	21.00	10.40	31.00	-10.60
1.50	9.50	11.50	-9.76	21.50	9.66	31.50	-9.91
2.00	8.33	12.00	-8.66	22.00	8.53	32.00	-8.86
2.50	6.93	12.50	-7.33	22.50	7.17	32.50	-7.55
3.00	5.46	13.00	-5.86	23.00	5.69	33.00	-6.09
3.50	3.99	13.50	-4.39	23.50	4.23	33.50	-4.62
4.00	2.62	14.00	-2.98	24.00	2.83	34.00	-3.20
4.50	1.36	14.50	-1.70	24.50	1.55	34.50	-1.89
5.00	0.22	15.00	-0.51	25.00	0.40	35.00	-0.70
5.50	-0.87	15.50	0.57	25.50	-0.70	35.50	0.40
6.00	-1.94	16.00	1.65	26.00	-1.77	36.00	1.48
6.50	-3.08	16.50	2.77	26.50	-2.89	36.50	2.58
7.00	-4.29	17.00	3.96	27.00	-4.10	37.00	3.77
7.50	-5.61	17.50	5.25	27.50	-5.40	37.50	5.03
8.00	-6.97	18.00	6.59	28.00	-6.74	38.00	6.38
8.50	-8.26	18.50	7.92	28.50	-8.06	38.50	7.73
9.00	-9.40	19.00	9.11	29.00	-9.23	39.00	8.94
9.50	-10.30	19.50	10.10	29.50	-10.10	39.50	9.93
						40.00	10.60

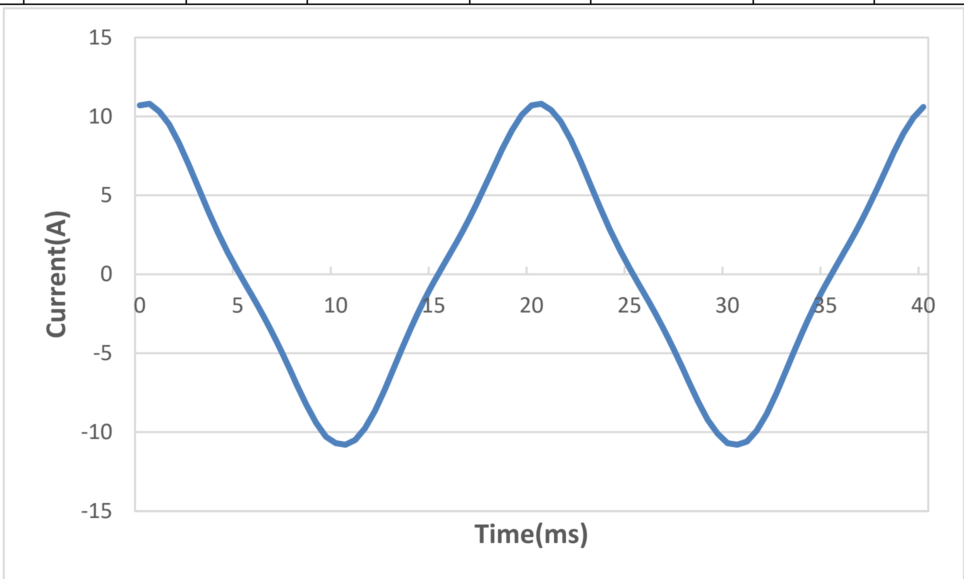


Fig.A3.9 Measured current waveform (Case V: fundamental + 3rd harmonic (AC side) +DC(DC-side); ADH2)