The AC Small-Signal Electrical Data Analysis in the Dielectric Representation of the Ni-Cd Battery

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Abstract

The *ac* small-signal electrical data of the Ni-Cd battery presented in the complex plane indicated skewed semicircular loci. This skewed behavior is examined via complex nonlinear least squares (CNLS) fitting using depression parameters of both Davidson-Cole (D-C) and Havriliak-Negami (H-N) empirical equations. The distribution function decreases when the H-N depression parameter β increases for fixed value of the other depression parameter α. The same function increases when the depression parameter α increases for fixed value of β. Also extremely small error was obtained for the complex domain analysis for both α and β parameters.

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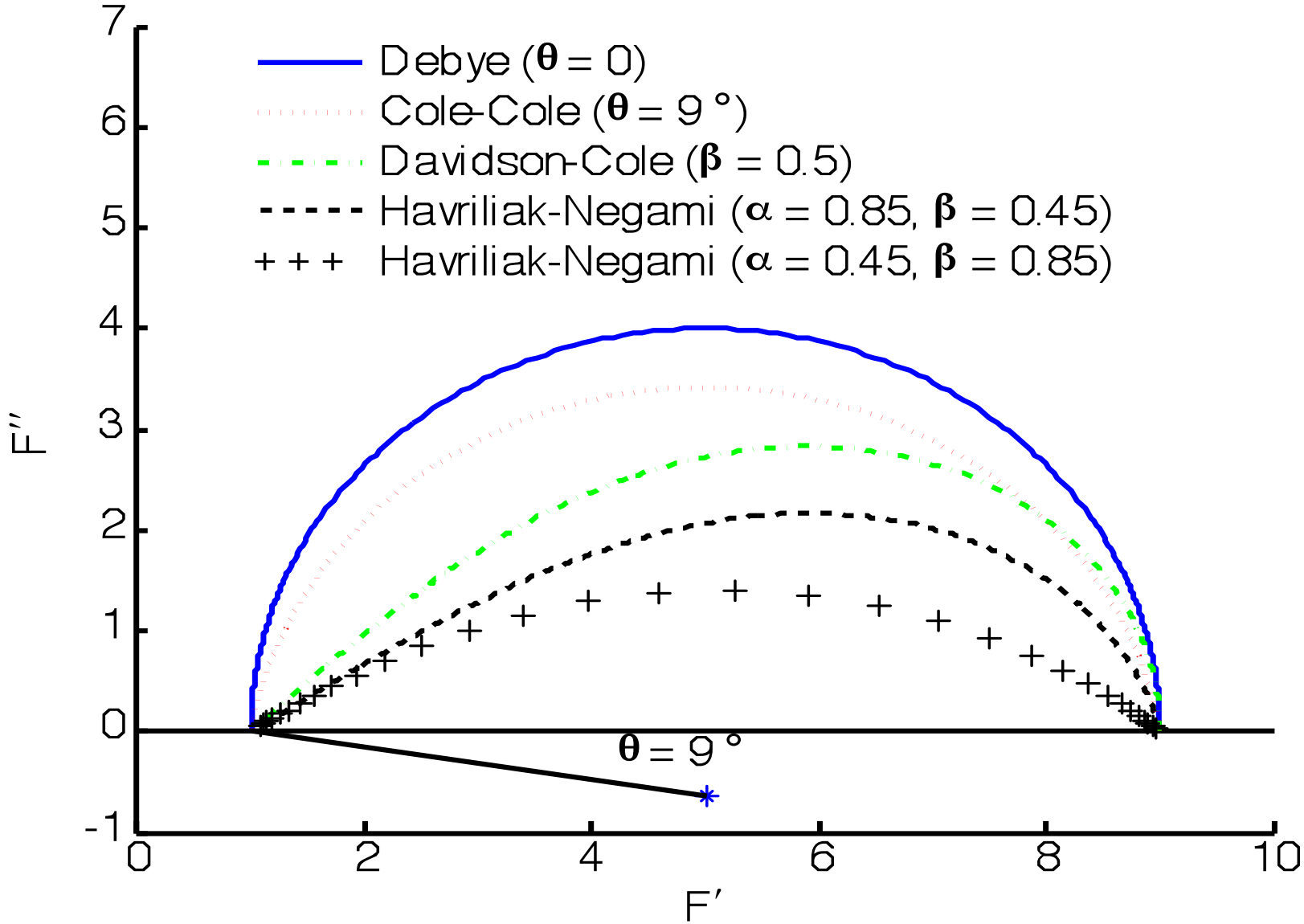
Frequency Domain Analysis performed for the *AC Small-Signal Electrical Data* using Davidson-Cole and Havriliak-Negami Dielectric Relaxation Functions

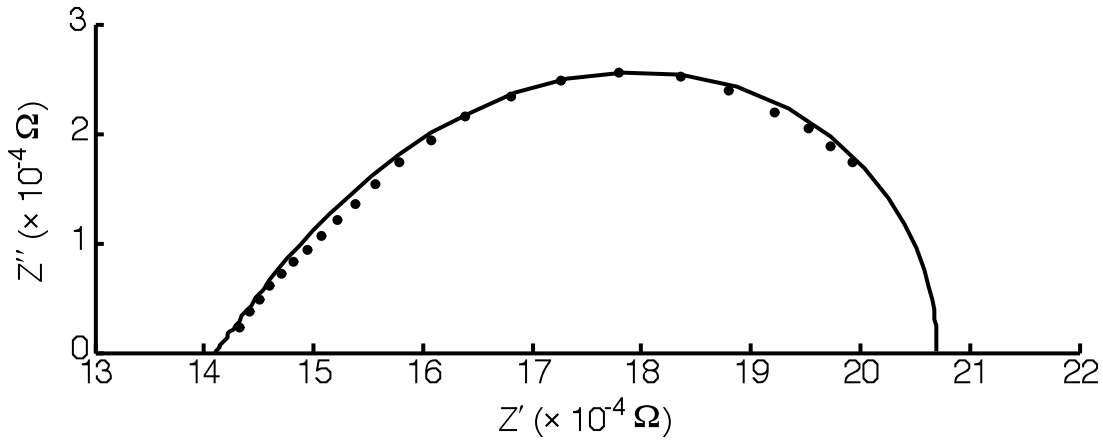
$$Z^*(\omega) = Z_\infty + \frac{(Z_s - Z_\infty)}{\left[1 + (j\,\omega\,\tau)^\alpha\right]^\beta}$$

$$F^*(\omega) = \frac{1}{[1 + (j\omega\tau)^\alpha]^\beta}$$

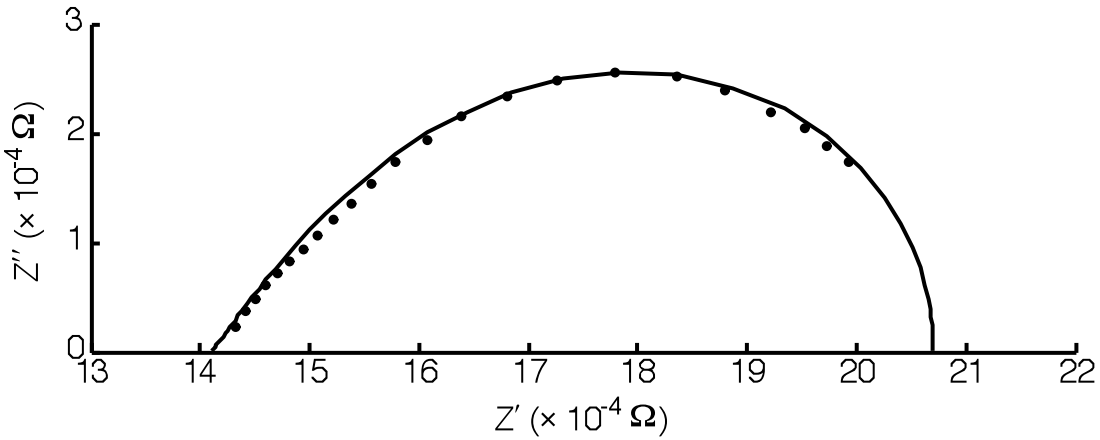


The nature of Debye (ideal) and non-Debye (non-ideal) type relaxations. Cole-Cole, Davidson-Cole, and Havriliak-Negami relaxations are the non-Debye type and probed with the parameters α and β.

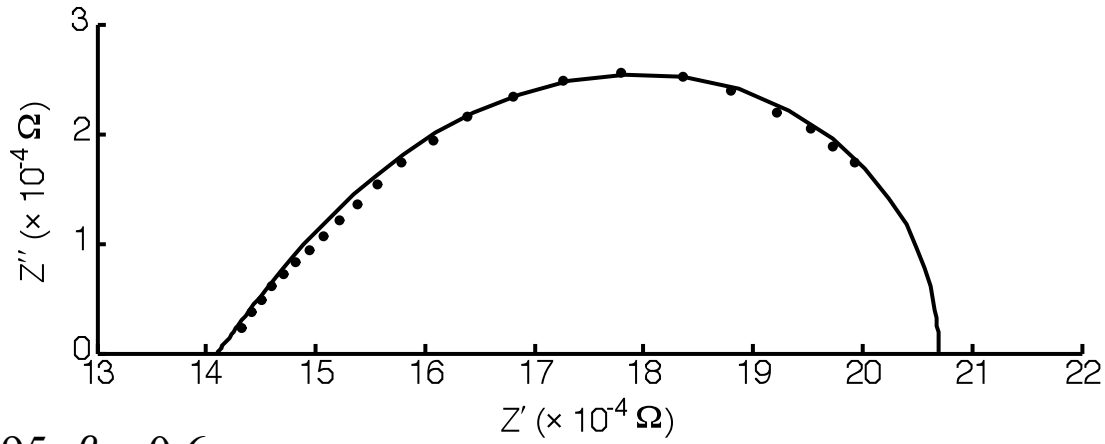
Davidson-Cole (D-C) and Havriliak-Negami (H-N) relaxations indicated by the parameters α and β for the same *ac* small-signal electrical data.



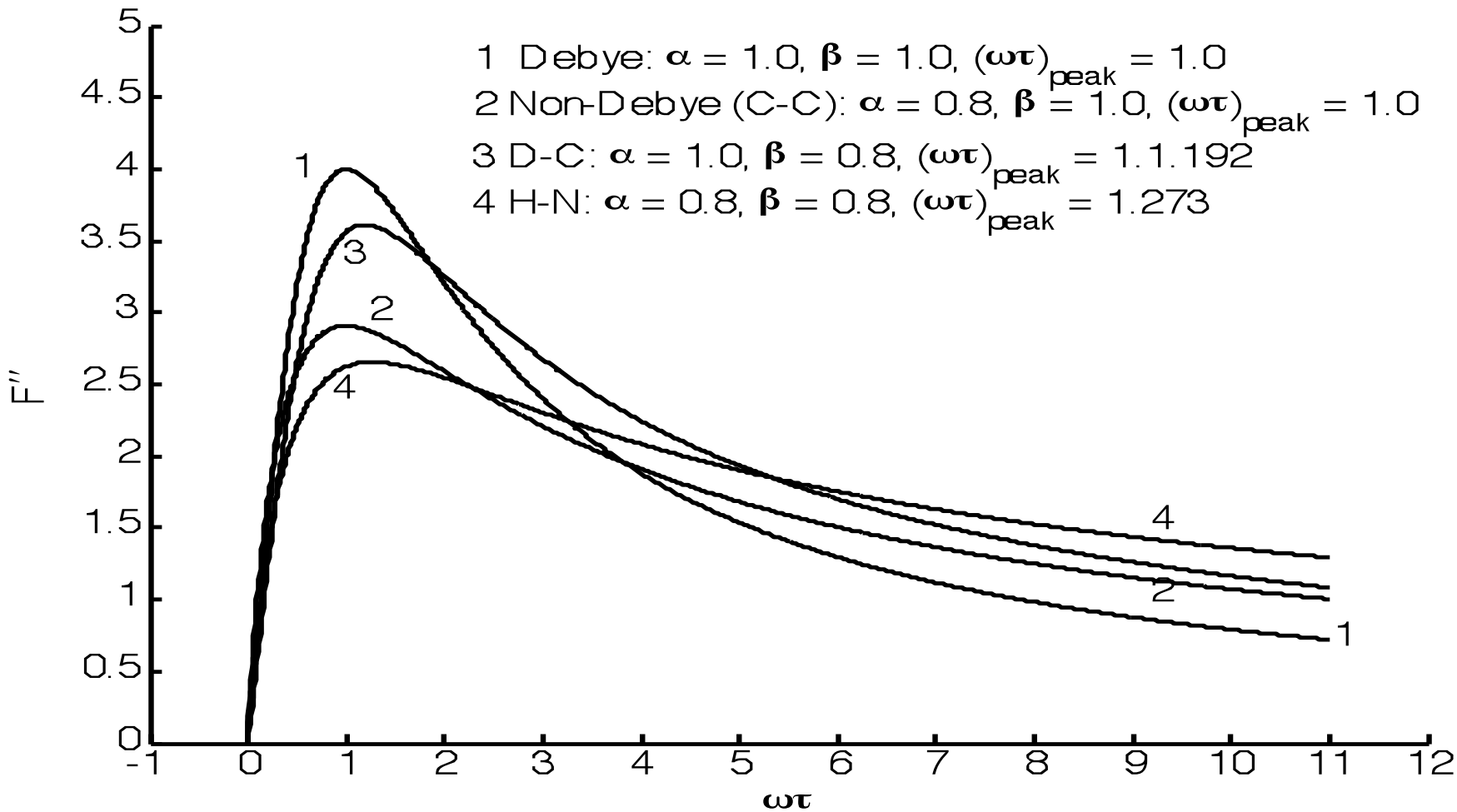
(*a*) $\alpha = 1.0, \beta = 0.6$



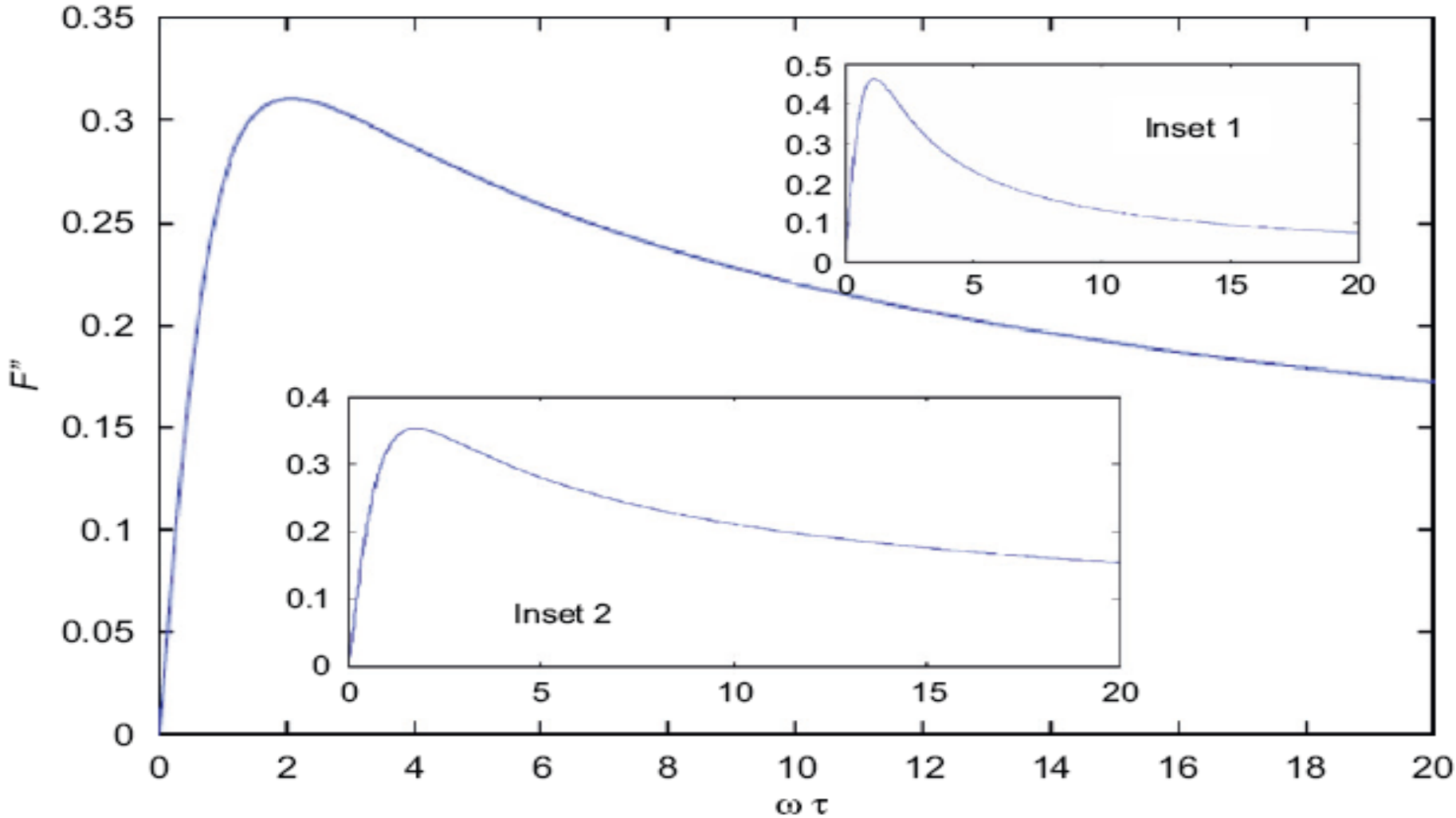
(*b*) $\alpha = 0.999, \beta = 0.6$



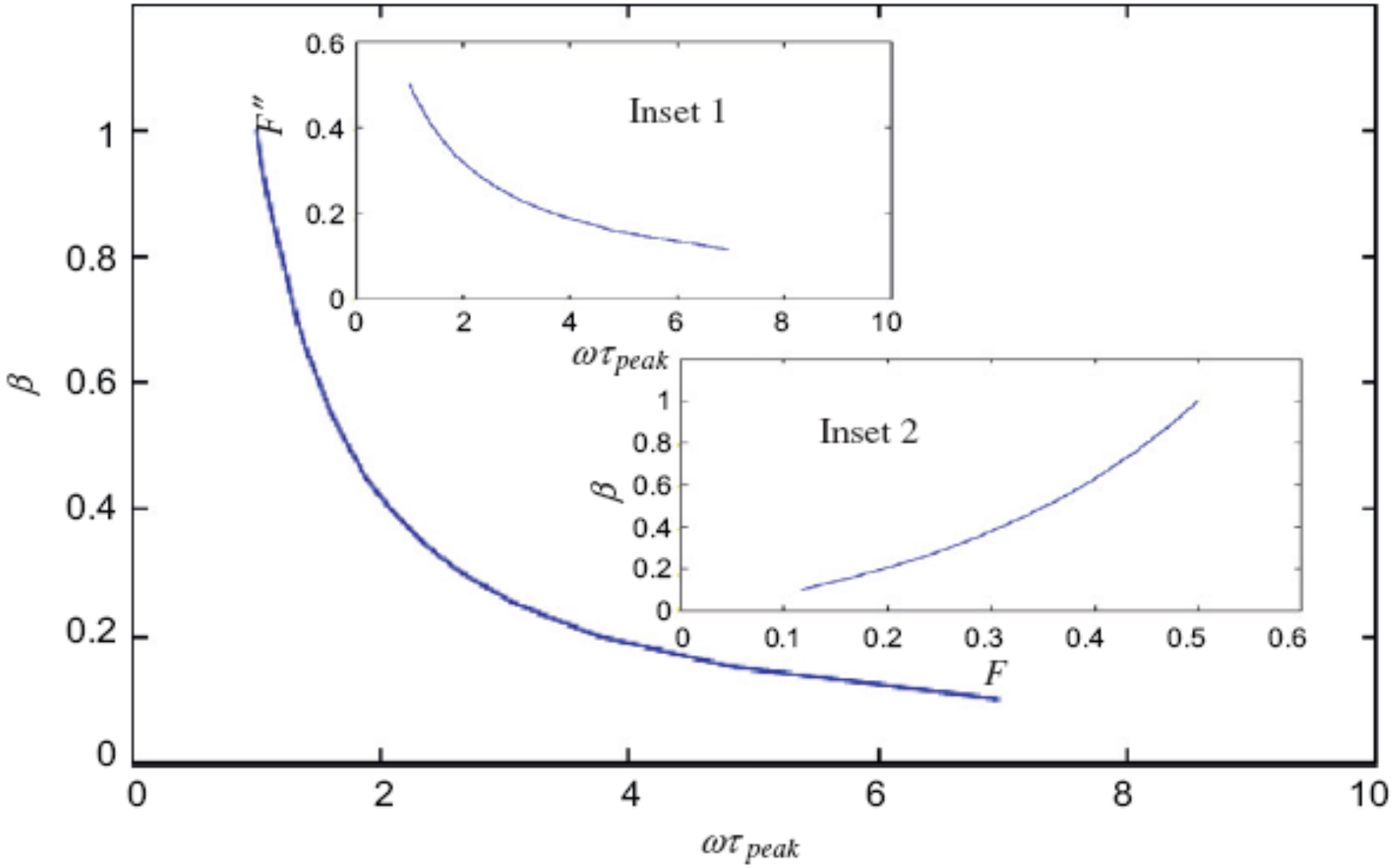
(*c*) $\alpha = 0.995, \beta = 0.6$



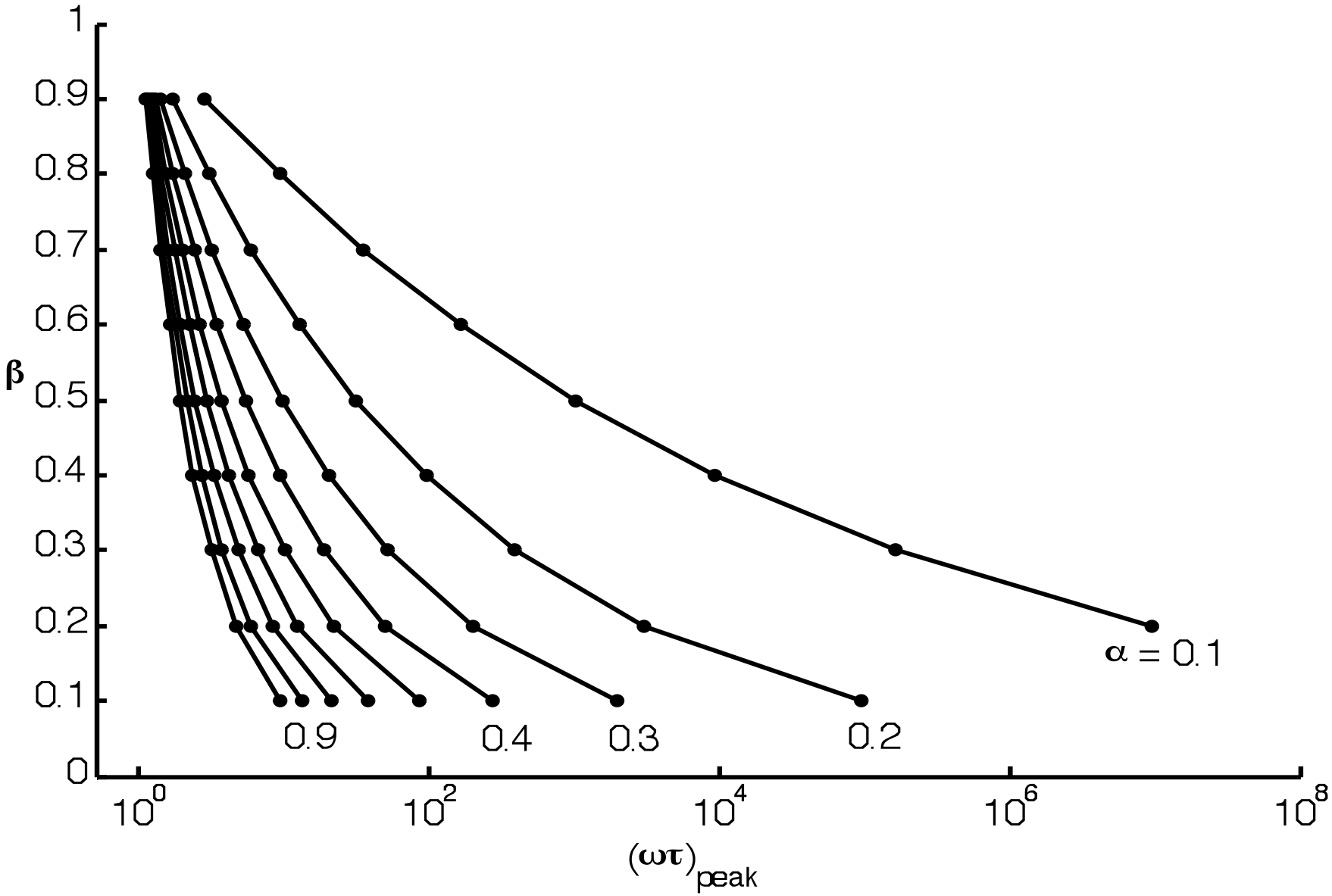
The product ω × τ is displayed as a function of the imaginary part of the relaxation function $F^*(\omega)$ for (1) Debye response with α = 1.0 and β = 1.0 yielding (ωτ)peak = 1.0; (2) Non-Debye (i.e., Cole-Cole) response with α = 0.8 and β = 1.0 yielding (ωτ)peak = 1.0; (3) Davidson-Cole response with α = 1.0 and β = 0.8 yielding (*ωτ*)peak = 1.192; and (4) Havriliak-Negami response with α = 0.8 and β = 0.8 yielding (ωτ)peak = 1.273.



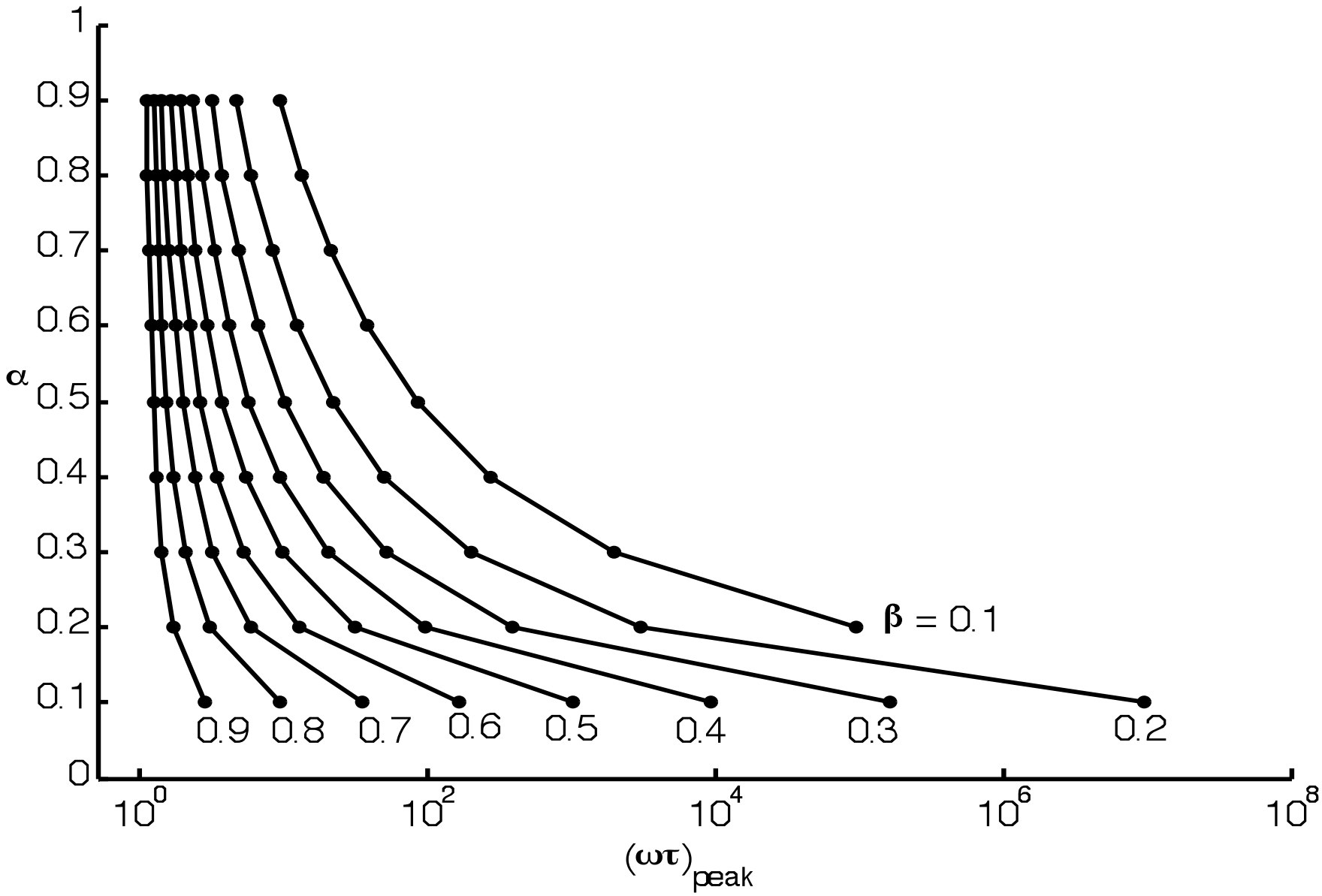
The product ω × τ is displayed as a function of the imaginary part of the impedance for β = 0.40 showing $\omega\tau_{peak} = 2.080$ and $Z = Z'' = \mathrm{Im}\, Z^* = 0.3107$. Inset 1 shows $\beta = 0.85$ with $\omega\tau_{peak} = 1.140$ and $Z = Z'' = \mathrm{Im}\, Z^* = 0.4645$; and inset 2 shows β = 0.50 with $\omega\tau_{peak} = 1.140$ and $Z = Z'' = \mathrm{Im}\, Z^* = 0.3536$.



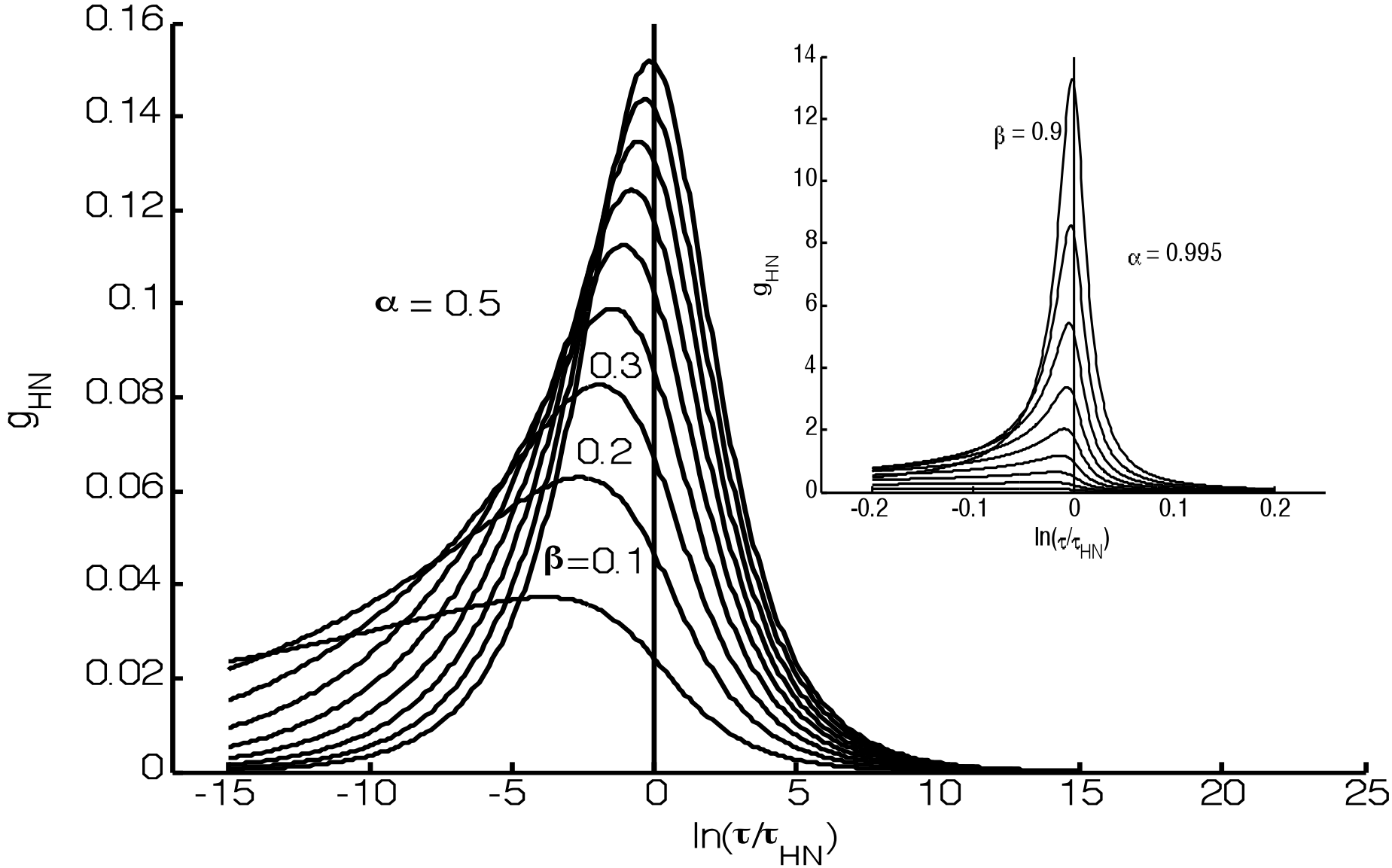
The variation Davidson-Cole depression parameter β as a function of the product $\omega \times \tau$. Inset 1 shows variation of F'' as a function of product $\omega \times \tau$; and inset 2 shows the relation between β and F''.



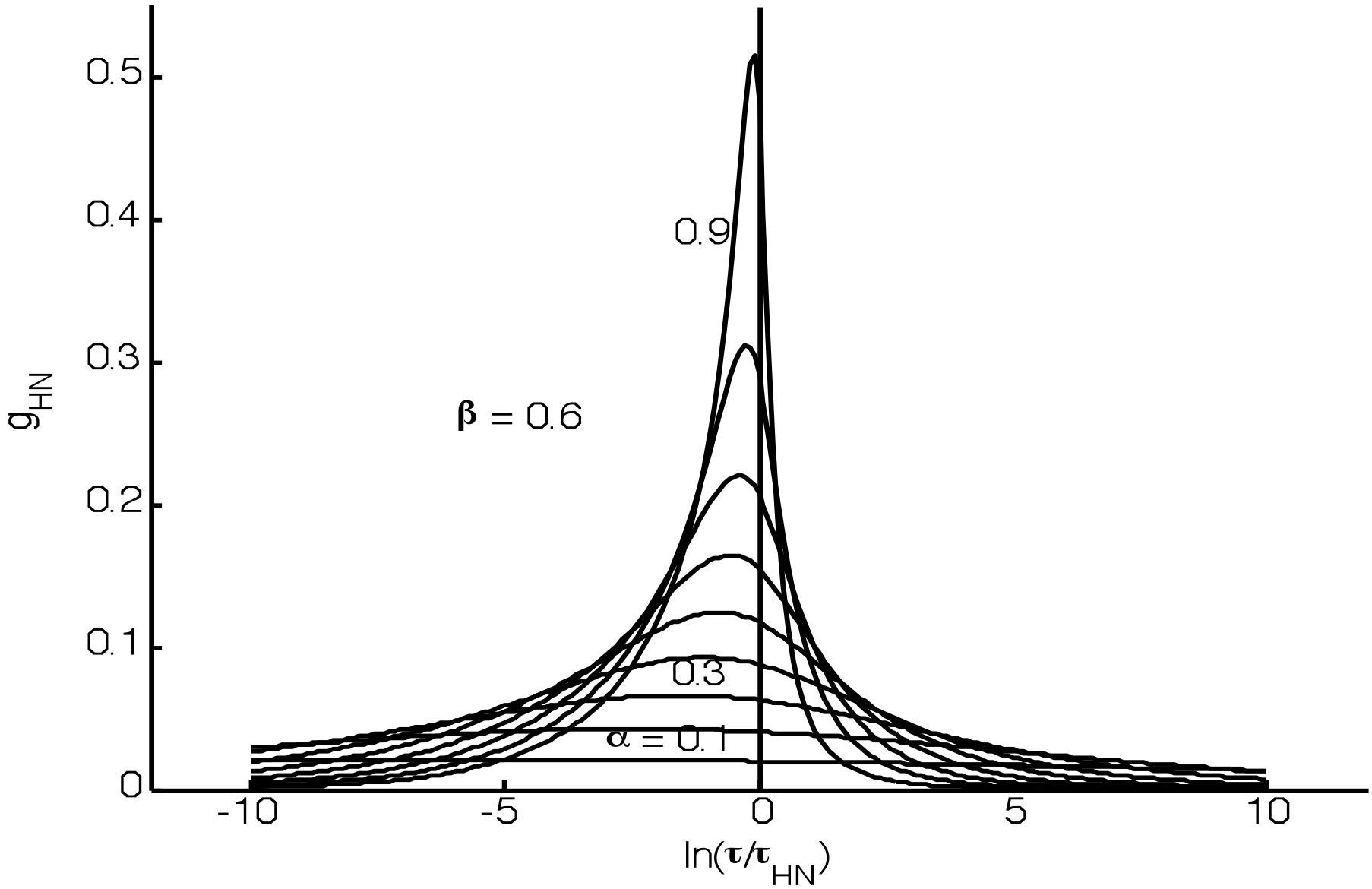
The parameter β versus $(\omega\tau)_{peak}$ for various values of α.



The parameter α versus $(\omega\tau)_{peak}$ for various values of β.



The effect of β on the H-N distribution function g_{HN} for α = 0.5.



The effect of α on the H-N distribution function g_{HN} for β = 0.6.

The *AC* electrical data for the Ni–Cd battery.

Observation Number	*f* (Hz)	Measured Data ($\times 10^{-4}$ Ω)		D-C Data ($\times 10^{-4}$ Ω)				H-N Data ($\times 10^{-4}$ Ω)			
				Calculated		Error		Calculated		Error	
				R^2				R^2			
				0.998545	0.994314			0.997304	0.976946		
		Z′	Z″	Z′	Z″	Z′	Z″	Z′	Z″	Z′	Z″
1	50.11000	14.32000	0.24000	14.38200	0.32400	0.062	0.084	14.40586	0.48162	0.086	0.242
2	39.80000	14.42000	0.38000	14.44000	0.38580	0.020	0.006	14.46283	0.54686	0.043	0.167
3	31.61000	14.50000	0.49000	14.50500	0.45830	0.005	0.032	14.52813	0.62064	0.028	0.131
4	25.11000	14.59000	0.61000	14.57900	0.54290	0.011	0.067	14.60304	0.70386	0.013	0.094
5	19.95000	14.71000	0.72000	14.66300	0.64130	0.047	0.079	14.68913	0.79750	0.021	0.078
6	15.85000	14.82000	0.84000	14.76000	0.75530	0.060	0.085	14.78842	0.90265	0.032	0.063
7	12.59000	14.94000	0.95000	14.87300	0.88670	0.067	0.063	14.90334	1.02037	0.037	0.070
8	10.00000	15.07000	1.07000	15.00400	1.03700	0.066	0.033	15.03670	1.15135	0.033	0.081
9	7.94300	15.22000	1.21000	15.15800	1.20710	0.062	0.003	15.19195	1.29599	0.028	0.086
10	6.30900	15.39000	1.37000	15.34200	1.39680	0.048	0.027	15.37332	1.45410	0.017	0.084
11	5.01100	15.57000	1.54000	15.56100	1.60410	0.009	0.064	15.58587	1.62443	0.016	0.084
12	3.98000	15.79000	1.74000	15.82400	1.82350	0.034	0.083	15.83540	1.80402	0.045	0.064
13	3.16100	16.07000	1.95000	16.13900	2.04480	0.069	0.095	16.12824	1.98746	0.058	0.037
14	2.51100	16.39000	2.16000	16.51200	2.25180	0.122	0.092	16.47003	2.16557	0.080	0.006
15	1.99500	16.80000	2.35000	16.93900	2.42260	0.139	0.073	16.86462	2.32491	0.065	0.025
16	1.58500	17.27000	2.50000	17.40900	2.53390	0.139	0.034	17.31151	2.44755	0.042	0.052
17	1.25900	17.79000	2.57000	17.89700	2.56750	0.107	0.002	17.80198	2.51249	0.012	0.058
18	1.00000	18.35000	2.53000	18.37000	2.51860	0.020	0.011	18.31539	2.50046	0.035	0.030
19	0.79430	18.80000	2.40000	18.79600	2.39940	0.004	0.001	18.82081	2.40163	0.021	0.002
20	0.63090	19.22000	2.20000	19.15600	2.23310	0.064	0.033	19.28393	2.22184	0.064	0.022
21	0.50110	19.52000	2.06000	19.44400	2.04590	0.076	0.014	19.67722	1.98273	0.157	0.077
22	0.39800	19.73000	1.89000	19.66500	1.85860	0.065	0.031	19.98790	1.71435	0.258	0.176
23	0.31610	19.92000	1.74000	19.83200	1.68490	0.088	0.055	20.21853	1.44506	0.299	0.295

Thank you.