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Inventor(s)	Kolamkar; Maithili Dinanath et al.

Electronic battery tester

Abstract

An electronic battery tester for testing a storage battery in an automotive vehicle includes first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the applied forcing function. Starter voltage measurement circuitry electrically couples to a starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor. Second test circuitry receives the battery test output from the first test circuitry and the starter voltage profile information and provides an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.

Inventors: **Kolamkar; Maithili Dinanath (Glen Ellyn, IL), Losinski; Lance (Crown Point, IN), Lacroix, IV; Paul George (Chicago, IL), Pham; Anh Hoang Duy (Chicago, IL)**

Applicant: **Midtronics, Inc.** (Willowbrook, IL)

Family ID: **1000008762613**

Assignee: **Midtronics, Inc. (Willowbrook, IL)**

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5832396	12/1997	Moroto et al.	701/22	N/A
5850113	12/1997	Weimer et al.	307/125	N/A
5862515	12/1998	Kobayashi et al.	702/63	N/A
5865638	12/1998	Trafton	439/288	N/A
5869951	12/1998	Takahashi	320/104	N/A
5870018	12/1998	Person	307/10.2	N/A
5871858	12/1998	Thomsen et al.	429/7	N/A
5872443	12/1998	Williamson	320/160	N/A
5872453	12/1998	Shimoyama et al.	324/431	N/A
5883306	12/1998	Hwang	73/146.8	N/A
5884202	12/1998	Arjomand	701/31.4	N/A
5894222	12/1998	Hibino	N/A	N/A
5895440	12/1998	Proctor et al.	702/63	N/A
5903154	12/1998	Zhang et al.	324/437	N/A
5903716	12/1998	Kimber et al.	395/114	N/A
5912534	12/1998	Benedict	315/82	N/A
5914605	12/1998	Bertness	324/430	N/A
5916287	12/1998	Arjomand et al.	701/33.2	N/A
5927938	12/1998	Hammerslag	414/809	N/A
5929609	12/1998	Joy et al.	322/25	N/A
5935180	12/1998	Fieramosca et al.	701/29.6	N/A
5939855	12/1998	Proctor et al.	320/104	N/A
5939861	12/1998	Joko et al.	320/122	N/A
5945829	12/1998	Bertness	324/430	N/A
5946605	12/1998	Takahisa et al.	455/68	N/A
5950144	12/1998	Hall et al.	702/108	N/A
5951229	12/1998	Hammerslag	414/398	N/A
5953322	12/1998	Kimball	370/328	N/A
5955951	12/1998	Wischerop et al.	340/572.8	N/A
5961561	12/1998	Wakefield, II	701/29	N/A
5961604	12/1998	Anderson et al.	709/229	N/A

5963012	12/1998	Garcia et al.	320/106	N/A
5969625	12/1998	Russo	340/636.19	N/A
5973598	12/1998	Beigel	340/572.1	N/A
5978805	12/1998	Carson	707/10	N/A
5982138	12/1998	Krieger	320/105	N/A
5990664	12/1998	Rahman	320/136	N/A
6002238	12/1998	Champlin	320/134	N/A
6005489	12/1998	Siegle et al.	340/825.69	N/A
6005759	12/1998	Hart et al.	361/66	N/A
6008652	12/1998	Theofanopoulos et al.	324/434	N/A
6009369	12/1998	Boisvert et al.	701/99	N/A
6009742	12/1999	Balko	N/A	N/A
6016047	12/1999	Notten et al.	320/137	N/A
6031354	12/1999	Wiley et al.	320/116	N/A
6031368	12/1999	Klippel et al.	324/133	N/A
6037745	12/1999	Koike et al.	320/104	N/A
6037749	12/1999	Parsonage	320/132	N/A
6037751	12/1999	Klang	320/160	N/A
6037777	12/1999	Champlin	324/430	N/A
6037778	12/1999	Makhija	324/433	N/A
6046514	12/1999	Rouillard et al.	307/77	N/A
6051976	12/1999	Bertness	324/426	N/A
6055468	12/1999	Kaman et al.	701/29	N/A
6061638	12/1999	Joyce	702/63	N/A
6064372	12/1999	Kahkoska	345/173	N/A
6072299	12/1999	Kurle et al.	320/112	N/A
6072300	12/1999	Tsuji	320/116	N/A
6075339	12/1999	Reipur et al.	320/110	N/A
6076018	12/1999	Sturman et al.	N/A	N/A
6081098	12/1999	Bertness et al.	320/134	N/A
6081109	12/1999	Seymour et al.	324/127	N/A
6081154	12/1999	Ezell et al.	327/540	N/A
6087815	12/1999	Pfeifer et al.	323/282	N/A
6091238	12/1999	McDermott	324/207.2	N/A
6091245	12/1999	Bertness	324/426	N/A
6094030	12/1999	Gimthorpe et al.	N/A	N/A
6094033	12/1999	Ding et al.	320/132	N/A
6097193	12/1999	Bramwell	324/429	N/A
6100670	12/1999	Levesque	320/150	N/A
6100815	12/1999	Pailthorp	324/754.07	N/A
6104167	12/1999	Bertness et al.	320/132	N/A
6113262	12/1999	Purola et al.	374/45	N/A
6114834	12/1999	Parise	320/109	N/A
6118252	12/1999	Richter	N/A	N/A
6121880	12/1999	Scott et al.	340/572.5	N/A
6130519	12/1999	Whiting et al.	N/A	N/A
6136914	12/1999	Hergenrother et al.	524/495	N/A
6137261	12/1999	Kurle et al.	N/A	N/A
6137269	12/1999	Champlin	320/150	N/A

6140797	12/1999	Dunn	320/105	N/A
6141608	12/1999	Rother	701/29.6	N/A
6144185	12/1999	Dougherty et al.	320/132	N/A
6147598	12/1999	Murphy et al.	340/426.19	N/A
6149653	12/1999	Deslauriers	606/232	N/A
6150793	12/1999	Lesesky et al.	320/104	N/A
6158000	12/1999	Collins	713/1	N/A
6161640	12/1999	Yamaguchi	180/65.8	N/A
6163156	12/1999	Bertness	324/426	N/A
6164063	12/1999	Mendler	60/274	N/A
6167349	12/1999	Alvarez	702/63	N/A
6172483	12/2000	Champlin	320/134	N/A
6172505	12/2000	Bertness	324/430	N/A
6177737	12/2000	Palfey et al.	307/64	N/A
6177878	12/2000	Tamura	N/A	N/A
6181545	12/2000	Amatucci et al.	361/502	N/A
6184655	12/2000	Malackowski	320/116	N/A
6184656	12/2000	Karunasiri et al.	320/119	N/A
6191557	12/2000	Gray et al.	320/132	N/A
6202739	12/2000	Pal et al.	165/104.33	N/A
6211651	12/2000	Nemoto	320/133	N/A
6211653	12/2000	Stasko	320/132	N/A
6215275	12/2000	Bean	320/106	N/A
6218805	12/2000	Melcher	320/105	N/A
6218936	12/2000	Imao	340/447	N/A
6222342	12/2000	Eggert et al.	320/105	N/A
6222369	12/2000	Champlin	324/430	N/A
D442503	12/2000	Lundbeck et al.	D10/77	N/A
6225808	12/2000	Varghese et al.	324/426	N/A
6225898	12/2000	Kamiya et al.	340/505	N/A
6236186	12/2000	Helton et al.	320/106	N/A
6236332	12/2000	Conkright et al.	340/3.1	N/A
6236949	12/2000	Hart	702/64	N/A
6238253	12/2000	Qualls	439/759	N/A
6242887	12/2000	Burke	320/104	N/A
6242921	12/2000	Thibedeau et al.	324/429	N/A
6249124	12/2000	Bertness	324/426	N/A
6250973	12/2000	Lowery et al.	439/763	N/A
6252942	12/2000	Zoiss	379/19	N/A
6254438	12/2000	Gaunt	439/755	N/A
6255826	12/2000	Ohsawa	320/116	N/A
6259170	12/2000	Limoge et al.	307/10.8	N/A
6259254	12/2000	Klang	324/427	N/A
6262563	12/2000	Champlin	320/134	N/A
6262692	12/2000	Babb	343/895	N/A
6263268	12/2000	Nathanson	701/29	N/A
6263322	12/2000	Kirkevold et al.	705/400	N/A
6271643	12/2000	Becker et al.	320/112	N/A
6271748	12/2000	Derbyshire et al.	340/442	N/A
6272387	12/2000	Yoon	700/83	N/A

6275008	12/2000	Arai et al.	320/132	N/A
6285191	12/2000	Gollomp et al.	324/427	N/A
6294896	12/2000	Champlin	320/134	N/A
6294897	12/2000	Champlin	320/153	N/A
6304087	12/2000	Bertness	324/426	N/A
6307349	12/2000	Koenck et al.	320/112	N/A
6310481	12/2000	Bertness	324/430	N/A
6313607	12/2000	Champlin	320/132	N/A
6313608	12/2000	Varghese et al.	320/132	N/A
6316914	12/2000	Bertness	320/134	N/A
6320385	12/2000	Ng et al.	320/104	N/A
6323650	12/2000	Bertness et al.	324/426	N/A
6324042	12/2000	Andrews	361/93.2	N/A
6329793	12/2000	Bertness et al.	320/132	N/A
6331762	12/2000	Bertness	320/134	N/A
6332113	12/2000	Bertness	702/63	N/A
6346795	12/2001	Haraguchi et al.	320/136	N/A
6347958	12/2001	Tsai	439/488	N/A
6351102	12/2001	Troy	320/139	N/A
6356042	12/2001	Kahlon et al.	318/138	N/A
6356083	12/2001	Ying	324/426	N/A
6359441	12/2001	Bertness	324/426	N/A
6359442	12/2001	Henningson et al.	324/426	N/A
6363303	12/2001	Bertness	701/29	N/A
RE37677	12/2001	Irie	315/83	N/A
6377031	12/2001	Karuppana et al.	323/220	N/A
6384608	12/2001	Namaky	324/430	N/A
6388448	12/2001	Cervas	324/426	N/A
6389337	12/2001	Kolls	701/31.6	N/A
6392414	12/2001	Bertness	324/429	N/A
6396278	12/2001	Makhija	324/402	N/A
6407554	12/2001	Godau et al.	324/503	N/A
6411098	12/2001	Laletin	324/436	N/A
6417669	12/2001	Champlin	324/426	N/A
6420852	12/2001	Sato	320/134	N/A
6424157	12/2001	Gollomp et al.	324/430	N/A
6424158	12/2001	Klang	324/433	N/A
6426606	12/2001	Purkey	N/A	N/A
6433512	12/2001	Birkler et al.	320/132	N/A
6437957	12/2001	Karuppana et al.	361/78	N/A
6441585	12/2001	Bertness	320/132	N/A
6445158	12/2001	Bertness et al.	320/104	N/A
6448778	12/2001	Rankin	324/503	N/A
6449726	12/2001	Smith	713/340	N/A
6456036	12/2001	Thandiwe	320/106	N/A
6456045	12/2001	Troy et al.	320/139	N/A
6465908	12/2001	Karuppana et al.	307/31	N/A
6466025	12/2001	Klang	324/429	N/A
6466026	12/2001	Champlin	324/430	N/A
6469511	12/2001	Vonderhaar et al.	324/425	N/A

6473659	12/2001	Shah et al.	700/79	N/A
6477478	12/2001	Jones et al.	702/102	N/A
6495990	12/2001	Champlin	320/132	N/A
6497209	12/2001	Karuppana et al.	123/179.3	N/A
6500025	12/2001	Moenkhaus et al.	439/502	N/A
6501243	12/2001	Kaneko	318/139	N/A
6505507	12/2002	Imao	73/146.5	N/A
6507196	12/2002	Thomsen et al.	324/436	N/A
6526361	12/2002	Jones et al.	702/63	N/A
6529723	12/2002	Bentley	455/405	N/A
6531847	12/2002	Tsukamoto et al.	N/A	N/A
6531848	12/2002	Chitsazan et al.	320/153	N/A
6532425	12/2002	Boost et al.	702/63	N/A
6533316	12/2002	Breed et al.	280/735	N/A
6534992	12/2002	Meissner et al.	324/426	N/A
6534993	12/2002	Bertness	324/433	N/A
6536536	12/2002	Gass et al.	173/2	N/A
6544078	12/2002	Palmisano et al.	439/762	N/A
6545599	12/2002	Derbyshire et al.	340/442	N/A
6556019	12/2002	Bertness	324/426	N/A
6566883	12/2002	Vonderhaar et al.	324/426	N/A
6570385	12/2002	Roberts et al.	324/378	N/A
6573685	12/2002	Nakanishi et al.	N/A	N/A
6577107	12/2002	Kechmire	320/139	N/A
6586941	12/2002	Bertness et al.	324/426	N/A
6597150	12/2002	Bertness et al.	320/104	N/A
6599243	12/2002	Woltermann et al.	600/300	N/A
6600815	12/2002	Walding	379/93.07	N/A
6611740	12/2002	Lowrey et al.	701/29	N/A
6614349	12/2002	Proctor et al.	340/572.1	N/A
6618644	12/2002	Bean	700/231	N/A
6621272	12/2002	Champlin	324/426	N/A
6623314	12/2002	Cox et al.	439/759	N/A
6624635	12/2002	Lui	324/426	N/A
6628011	12/2002	Droppo et al.	307/43	N/A
6629054	12/2002	Makhija et al.	702/113	N/A
6633165	12/2002	Bertness	324/426	N/A
6635974	12/2002	Karuppana et al.	307/140	N/A
6636790	12/2002	Lightner et al.	701/31.5	N/A
6667624	12/2002	Raichle et al.	324/522	N/A
6679212	12/2003	Kelling	123/179.28	N/A
6686542	12/2003	Zhang	174/74	N/A
6696819	12/2003	Bertness	320/134	N/A
6707303	12/2003	Bertness et al.	324/426	N/A
6732031	12/2003	Lightner et al.	701/31.4	N/A
6736941	12/2003	Oku et al.	203/68	N/A
6737831	12/2003	Champlin	320/132	N/A
6738697	12/2003	Breed	701/29	N/A
6740990	12/2003	Tozuka et al.	307/9.1	N/A
6744149	12/2003	Karuppana et al.	307/31	N/A

6745153	12/2003	White et al.	702/184	N/A
6759849	12/2003	Bertness	324/426	N/A
6771073	12/2003	Henningson et al.	324/426	N/A
6777945	12/2003	Roberts et al.	324/426	N/A
6781344	12/2003	Hedegor et al.	320/106	N/A
6781382	12/2003	Johnson	324/426	N/A
6784635	12/2003	Larson	320/104	N/A
6784637	12/2003	Raichle et al.	320/107	N/A
6788025	12/2003	Bertness et al.	320/104	N/A
6795782	12/2003	Bertness et al.	702/63	N/A
6796841	12/2003	Cheng et al.	439/620.3	N/A
6805090	12/2003	Bertness et al.	123/198	N/A
6806716	12/2003	Bertness et al.	324/426	N/A
6825669	12/2003	Raichle et al.	324/426	N/A
6832141	12/2003	Skeen et al.	701/31.4	N/A
6842707	12/2004	Raichle et al.	702/62	N/A
6845279	12/2004	Gilmore et al.	700/115	N/A
6850037	12/2004	Bertness	320/132	N/A
6856162	12/2004	Greatorex et al.	324/764.01	N/A
6856972	12/2004	Yun et al.	705/36R	N/A
6871151	12/2004	Bertness	702/63	N/A
6885195	12/2004	Bertness	324/426	N/A
6888468	12/2004	Bertness	340/636.15	N/A
6891378	12/2004	Bertness et al.	324/426	N/A
6895809	12/2004	Raichle	73/119	N/A
6904796	12/2004	Pacsai et al.	73/146.8	N/A
6906522	12/2004	Bertness et al.	324/426	N/A
6906523	12/2004	Bertness et al.	324/426	N/A
6906624	12/2004	McClelland et al.	340/442	N/A
6909287	12/2004	Bertness	324/427	N/A
6909356	12/2004	Brown et al.	340/3.2	N/A
6911825	12/2004	Namaky	324/426	N/A
6913483	12/2004	Restaino et al.	439/504	N/A
6914413	12/2004	Bertness et al.	320/104	N/A
6919725	12/2004	Bertness et al.	324/433	N/A
6930485	12/2004	Bertness et al.	324/426	N/A
6933727	12/2004	Bertness et al.	324/426	N/A
6941234	12/2004	Bertness et al.	702/63	N/A
6957133	12/2004	Hunt et al.	701/32.4	N/A
6961445	12/2004	Jensen et al.	N/A	N/A
6967484	12/2004	Bertness	324/426	N/A
6972662	12/2004	Ohkawa et al.	340/10.1	N/A
6983212	12/2005	Burns	702/63	N/A
6988053	12/2005	Namaky	320/104	N/A
6993421	12/2005	Pillar et al.	701/29.4	N/A
6998847	12/2005	Bertness et al.	324/426	N/A
7003410	12/2005	Bertness et al.	702/63	N/A
7003411	12/2005	Bertness	702/63	N/A
7012433	12/2005	Smith et al.	324/426	N/A
7015674	12/2005	VonderHaar	320/103	N/A

7029338	12/2005	Orange et al.	439/755	N/A
7034541	12/2005	Bertness et al.	324/426	N/A
7039533	12/2005	Bertness et al.	702/63	N/A
7042346	12/2005	Paulsen	340/438	N/A
7049822	12/2005	Kung	324/426	N/A
7058525	12/2005	Bertness et al.	702/63	N/A
7069979	12/2005	Tobias	165/104.33	N/A
7081755	12/2005	Klang et al.	324/426	N/A
7089127	12/2005	Thibedeau et al.	702/63	N/A
7098666	12/2005	Patino	324/433	N/A
7102556	12/2005	White	341/141	N/A
7106070	12/2005	Bertness et al.	324/538	N/A
7116109	12/2005	Klang	324/426	N/A
7119686	12/2005	Bertness et al.	340/572.1	N/A
7120488	12/2005	Nova et al.	600/2	N/A
7126341	12/2005	Bertness et al.	324/426	N/A
7129706	12/2005	Kalley	324/426	N/A
7154276	12/2005	Bertness	324/503	N/A
7170393	12/2006	Martin	340/10.1	N/A
7173182	12/2006	Katsuyama	174/36	N/A
7177925	12/2006	Carcido et al.	709/223	N/A
7182147	12/2006	Cutler et al.	173/1	N/A
7184866	12/2006	Squires	340/426.15	N/A
7184905	12/2006	Stefan	702/63	N/A
7198510	12/2006	Bertness	439/500	N/A
7200424	12/2006	Tischer et al.	455/567	N/A
7202636	12/2006	Reynolds et al.	320/166	N/A
7208914	12/2006	Klang	320/132	N/A
7209850	12/2006	Brott et al.	324/426	N/A
7209860	12/2006	Trsar et al.	702/183	N/A
7212887	12/2006	Shah et al.	700/276	N/A
7212911	12/2006	Raichle et al.	701/114	N/A
7219023	12/2006	Banke et al.	702/58	N/A
7233128	12/2006	Brost et al.	320/132	N/A
7235977	12/2006	Koran et al.	324/426	N/A
7246015	12/2006	Bertness et al.	702/63	N/A
7251551	12/2006	Mitsueda	700/2	N/A
7272519	12/2006	Lesesky et al.	702/63	N/A
7287001	12/2006	Falls et al.	705/22	N/A
7295936	12/2006	Bertness et al.	702/63	N/A
7301303	12/2006	Hulden	320/103	N/A
7319304	12/2007	Veloo et al.	320/134	N/A
7339477	12/2007	Puzio et al.	340/572.1	N/A
7363175	12/2007	Bertness et al.	702/63	N/A
7376497	12/2007	Chen	701/31.6	N/A
7398176	12/2007	Bertness	702/140	N/A
7408358	12/2007	Knopf	324/426	N/A
7425833	12/2007	Bertness et al.	324/426	N/A
7446536	12/2007	Bertness	324/426	N/A
7453238	12/2007	Melichar	320/132	N/A

7479763	12/2008	Bertness	320/134	N/A
7498767	12/2008	Brown et al.	320/107	N/A
7501795	12/2008	Bertness et al.	320/134	N/A
7504830	12/2008	Keuss	N/A	N/A
7505856	12/2008	Restaino et al.	702/63	N/A
7538571	12/2008	Raichle et al.	324/772	N/A
7545146	12/2008	Klang et al.	324/426	N/A
7557586	12/2008	Vonderhaar et al.	324/437	N/A
7571035	12/2008	Raichle	N/A	N/A
7590476	12/2008	Shumate	701/31.6	N/A
7592776	12/2008	Tsukamoto et al.	320/136	N/A
7595643	12/2008	Klang	324/426	N/A
7596437	12/2008	Hunt et al.	N/A	N/A
7598699	12/2008	Restaino et al.	320/105	N/A
7598743	12/2008	Bertness	324/426	N/A
7598744	12/2008	Bertness et al.	324/426	N/A
7619417	12/2008	Klang	324/427	N/A
7642786	12/2009	Philbrook	324/426	N/A
7642787	12/2009	Bertness et al.	324/426	N/A
7656162	12/2009	Vonderhaar et al.	324/426	N/A
7657386	12/2009	Thibedeau et al.	702/63	N/A
7667437	12/2009	Johnson et al.	320/150	N/A
7679325	12/2009	Seo	320/116	N/A
7684908	12/2009	Ogilvie et al.	701/29.6	N/A
7688074	12/2009	Cox et al.	324/426	N/A
7690573	12/2009	Raichle et al.	235/462	N/A
7696759	12/2009	Raichle et al.	324/538	N/A
7698179	12/2009	Leung et al.	705/28	N/A
7705602	12/2009	Bertness	324/426	N/A
7706991	12/2009	Bertness et al.	702/63	N/A
7706992	12/2009	Ricci et al.	N/A	N/A
7710119	12/2009	Bertness	324/426	N/A
7723993	12/2009	Klang	324/431	N/A
7728556	12/2009	Yano et al.	320/134	N/A
7728597	12/2009	Bertness	324/426	N/A
7729880	12/2009	Mashburn	702/151	N/A
7743788	12/2009	Schmitt	137/554	N/A
7751953	12/2009	Namaky	701/33.2	N/A
7772850	12/2009	Bertness	324/426	N/A
7774130	12/2009	Pepper	340/439	N/A
7774151	12/2009	Bertness	702/63	N/A
7777612	12/2009	Sampson et al.	340/426.1	N/A
7791348	12/2009	Brown et al.	324/426	N/A
7797995	12/2009	Schaefer	N/A	N/A
7808375	12/2009	Bertness et al.	340/455	N/A
7848857	12/2009	Nasr et al.	701/22	N/A
7883002	12/2010	Jin et al.	235/376	N/A
7902990	12/2010	Delmonico et al.	340/636.1	N/A
7914350	12/2010	Bozich	439/506	N/A
7924015	12/2010	Bertness	324/427	N/A

7940052	12/2010	Vonderhaar	N/A	N/A
7940053	12/2010	Brown et al.	324/426	N/A
7959476	12/2010	Smith et al.	N/A	N/A
7977914	12/2010	Bertness	N/A	N/A
D643759	12/2010	Bertness	N/A	N/A
7990155	12/2010	Henningson	324/429	N/A
7999505	12/2010	Bertness	320/104	N/A
8024083	12/2010	Chenn	701/2	N/A
8047868	12/2010	Korcynski	439/522	N/A
8164343	12/2011	Bertness	324/503	N/A
8198900	12/2011	Bertness et al.	N/A	N/A
8203345	12/2011	Bertness	N/A	N/A
8222868	12/2011	Buckner	320/136	N/A
8226008	12/2011	Raichle et al.	235/462.13	N/A
8237448	12/2011	Bertness	N/A	N/A
8306690	12/2011	Bertness	701/34.4	N/A
8310271	12/2011	Raichle et al.	324/765.01	N/A
8344685	12/2012	Bertness et al.	N/A	N/A
8436619	12/2012	Bertness et al.	N/A	N/A
8442877	12/2012	Bertness et al.	N/A	N/A
8449560	12/2012	Roth	227/175.1	N/A
8493022	12/2012	Bertness	N/A	N/A
D687727	12/2012	Kehoe et al.	N/A	N/A
8509212	12/2012	Sanjeev	N/A	N/A
8513949	12/2012	Bertness	N/A	N/A
8594957	12/2012	Gauthier	324/548	N/A
8674654	12/2013	Bertness	N/A	N/A
8674711	12/2013	Bertness	N/A	N/A
8704483	12/2013	Bertness et al.	N/A	N/A
8738309	12/2013	Bertness	N/A	N/A
8754653	12/2013	Volderhaar et al.	N/A	N/A
8810200	12/2013	Kondo	N/A	N/A
8825272	12/2013	Chinnadurai	N/A	N/A
8827729	12/2013	Gunreben	439/188	N/A
8872516	12/2013	Bertness	N/A	N/A
8872517	12/2013	Philbrook et al.	N/A	N/A
8901888	12/2013	Beckman	N/A	N/A
8958998	12/2014	Bertness	N/A	N/A
8963550	12/2014	Bertness et al.	N/A	N/A
9018958	12/2014	Bertness	N/A	N/A
9037394	12/2014	Fernandes	701/400	N/A
9052366	12/2014	Bertness	N/A	N/A
9056556	12/2014	Hyde et al.	N/A	N/A
9166261	12/2014	Ibi	N/A	N/A
9201120	12/2014	Stukenburg	N/A	N/A
9229062	12/2015	Stukenberg	N/A	N/A
9244100	12/2015	Coleman et al.	N/A	N/A
9255955	12/2015	Bertness	324/503	N/A
9274157	12/2015	Bertness	N/A	N/A
9312575	12/2015	Stukenberg	N/A	N/A

9335362	12/2015	Bertness	N/A	N/A
9419311	12/2015	Bertness	N/A	N/A
9425487	12/2015	Bertness	N/A	N/A
9496720	12/2015	McShane	N/A	N/A
9588185	12/2016	Champlin	N/A	N/A
9639899	12/2016	Gersitz	N/A	N/A
9923289	12/2017	Bertness	N/A	N/A
9966676	12/2017	Salo, III et al.	N/A	N/A
10046649	12/2017	Bertness	N/A	N/A
10222397	12/2018	Salo et al.	N/A	N/A
10317468	12/2018	Bertness	N/A	N/A
10429449	12/2018	Arnoldus	N/A	N/A
10473555	12/2018	Bertness	N/A	N/A
10525841	12/2019	Zhou et al.	N/A	N/A
10608353	12/2019	Lipkin et al.	N/A	N/A
10843574	12/2019	Palmisano et al.	N/A	N/A
11054480	12/2020	Bertness	N/A	N/A
11325479	12/2021	Bertness	N/A	N/A
11474153	12/2021	Salo, III et al.	N/A	N/A
11486930	12/2021	Salo, III et al.	N/A	N/A
11513160	12/2021	Salo, III et al.	N/A	N/A
11545839	12/2022	Sampson et al.	N/A	N/A
11548404	12/2022	Bertness	N/A	N/A
11566972	12/2022	Sampson et al.	N/A	N/A
11650259	12/2022	Bertness	N/A	N/A
11668779	12/2022	Bertness	N/A	N/A
11740294	12/2022	Bertness	N/A	N/A
11745593	12/2022	Awad Alla	N/A	N/A
11926224	12/2023	Bertness	N/A	N/A
11973202	12/2023	Bertness	N/A	N/A
12196813	12/2024	Bertness	N/A	N/A
12237482	12/2024	Bertness	N/A	N/A
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2004/0157113	12/2003	Klang	429/50	N/A
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Primary Examiner: Phan; Minh Q

Attorney, Agent or Firm: Westman, Champlin & Koehler, P.A.

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) The present application is based on and claims the benefit of U.S. provisional patent application Ser. No. 63/339,618, filed May 9, 2022, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND
(1) The present invention relates to battery testers of the type used to test storage batteries. More specifically, the present invention relates to a battery maintenance system with improved battery test accuracy.
(2) Electrical systems, such as those that are used in automotive vehicles, consist of a number of discrete components or systems which are interconnected. As used herein, the term “automotive vehicle” includes both vehicles which utilize an internal combustion engine, vehicles which utilize electric motors, as well as hybrid vehicles which include both types of systems. Techniques for measuring and utilizing parameters of electrical systems of automotive vehicles are known. Examples of various types of battery testers, monitors and other related equipment are set forth in U.S. Pat. No. 3,873,911, issued Mar. 25, 1975, to Champlin; U.S. Pat. No. 3,909,708, issued Sep. 30, 1975, to Champlin; U.S. Pat. No. 4,816,768, issued Mar. 28, 1989, to Champlin; U.S. Pat. No. 4,825,170, issued Apr. 25, 1989, to Champlin; U.S. Pat. No. 4,881,038, issued Nov. 14, 1989, to Champlin; U.S. Pat. No. 4,912,416, issued Mar. 27, 1990, to Champlin; U.S. Pat. No. 5,140,269, issued Aug. 18, 1992, to Champlin; U.S. Pat. No. 5,343,380, issued Aug. 30, 1994; U.S. Pat. No. 5,572,136, issued Nov. 5, 1996; U.S. Pat. No. 5,574,355, issued Nov. 12, 1996; U.S. Pat. No. 5,583,416, issued Dec. 10, 1996; U.S. Pat. No. 5,585,728, issued Dec. 17, 1996; U.S. Pat. No.

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FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Ser. No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Ser. No. 09/880,473, filed Jun. 13, 2001; entitled BATTERY TEST MODULE; U.S. Ser. No. 10/109,734, filed Mar. 28, 2002, entitled APPARATUS AND METHOD FOR COUNTERACTING SELF DISCHARGE IN A STORAGE BATTERY; U.S. Ser. No. 10/263,473, filed Oct. 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 09/653,963, filed Sep. 1, 2000, entitled SYSTEM AND METHOD FOR CONTROLLING POWER GENERATION AND STORAGE; U.S. Ser. No. 10/174,110, filed Jun. 18, 2002, entitled DAYTIME RUNNING LIGHT CONTROL USING AN INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Ser. No. 10/258,441, filed Apr. 9, 2003, entitled CURRENT MEASURING CIRCUIT SUITED FOR BATTERIES; U.S. Ser. No. 10/681,666, filed Oct. 8, 2003, entitled ELECTRONIC BATTERY TESTER WITH PROBE LIGHT; U.S. Ser. No. 11/207,419, filed Aug. 19, 2005, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION FOR USE DURING BATTERY TESTER/CHARGING, U.S. Ser. No. 11/356,443, filed Feb. 16, 2006, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Ser. No. 12/697,485, filed Feb. 1, 2010, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 12/769,911, filed Apr. 29, 2010, entitled STATIONARY BATTERY TESTER; U.S. Ser. No. 13/152,711, filed Jun. 3, 2011, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 14/039,746, filed Sep. 27, 2013, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 14/565,589, filed Dec. 10, 2014, entitled BATTERY TESTER AND BATTERY REGISTRATION TOOL; U.S. Ser. No. 15/017,887, filed Feb. 8, 2016, entitled METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM; U.S. Ser. No. 15/049,483, filed Feb. 22, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; U.S. Ser. No. 15/077,975, filed Mar. 23, 2016, entitled BATTERY MAINTENANCE SYSTEM; U.S. Ser. No. 15/149,579, filed May 9, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; U.S. Ser. No. 16/021,538, filed Jun. 28, 2018, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 16/253,526, filed Jan. 22, 2019, entitled HIGH CAPACITY BATTERY BALANCER; U.S. Ser. No. 16/297,975, filed Mar. 11, 2019, entitled HIGH USE BATTERY PACK MAINTENANCE; U.S. Ser. No. 17/086,629, filed Nov. 2, 2020, entitled HYBRID AND ELECTRIC VEHICLE BATTERY PACK MAINTENANCE DEVICE; U.S. Ser. No. 17/136,600, filed Dec. 29, 2020, entitled INTELLIGENT MODULE INTERFACE FOR BATTERY MAINTENANCE DEVICE; U.S. Ser. No. 17/364,953, filed Jul. 1, 2021, entitled ELECTRICAL LOAD FOR ELECTRONIC BATTERY TESTER AND ELECTRONIC BATTERY TESTER INCLUDING SUCH ELECTRICAL LOAD; U.S. Ser. No. 17/504,897, filed Oct. 19, 2021, entitled HIGH CAPACITY BATTERY BALANCER; U.S. Ser. No. 17/739,393, filed May 9, 2022, entitled HYBRID AND ELECTRIC VEHICLE BATTERY PACK MAINTENANCE DEVICE; U.S. Ser. No. 17/750,719, filed May 23, 2022, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 17/893,412, filed Aug. 23, 2022, entitled POWER ADAPTER FOR AUTOMOTIVE VEHICLE MAINTENANCE DEVICE; U.S. Ser. No. 18/166,702, filed Feb. 9, 2023, entitled BATTERY MAINTENANCE DEVICE WITH HIGH VOLTAGE CONNECTOR; all of which are incorporated herein by reference in their entireties.

(3) There is an ongoing need for improved battery testing and diagnostic equipment.

SUMMARY

(4) An electronic battery tester for testing a storage battery in an automotive vehicle includes first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the

applied forcing function Starter voltage measurement circuitry electrically couples to a starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor. Second test circuitry receives the battery test output from the first test circuitry and the starter voltage profile information and provides an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a simplified schematic diagram showing a battery maintenance system coupled to a battery of an automotive vehicle.

(2) FIG. **2** is a simplified block diagram of the battery maintenance system of FIG. **1**.

(3) FIG. **3** is a graph of voltage versus time showing a starter voltage profile.

(4) FIG. **4** illustrates a starter voltage profile data set stored with a battery condition data set.

(5) FIG. **5** is a perspective view of the automotive battery diagnostic or maintenance system of FIG. **1** in accordance with one example embodiment.

(6) FIG. **6** is a simplified block diagram of a system of FIG. **1**.

(7) FIG. **7** is a simplified block diagram of an amp clamp/current sensor.

(8) FIG. **8** is a simplified block diagram of an OBDII communicator of FIG. **1**.

(9) FIG. **9** is a diagram showing Kelvin connectors of FIG. **1**.

(10) FIG. **10** is a simplified block diagram of a base station shown in FIG. **1**.

(11) FIG. **11** is a simplified schematic diagram including measurement circuitry of the system of FIG. **1**.

(12) FIG. **12** is a simplified block diagram of a machine learning model training and a machine learning model prediction in accordance with a further embodiment of the invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

(13) Battery testers are known in the art and used for performing tests on batteries of automotive vehicles. There are various testing technique that are known including physical chemical measurements as well as electronic battery testers. Electronic battery testers generally use two primary techniques for measuring battery state of health and battery condition. One technique is to apply a load or a charge to the battery and observe how energy is removed from the battery, or added to the battery, to make a determination of battery condition. Another technique is to apply a signal to the battery and watch a response of the battery to the applied signal. As discussed in the Background section, Midtronics, Inc. along with Dr. Keith S. Champlin have pioneered the field of electronic battery testing. One technique employed is the application of a forcing function and the observation of the resultant change in a battery electrical dynamic parameter.

(14) However, there is an ongoing need for improved accuracy of battery tests. The battery tests should preferably be able to be performed in a short period of time and deliver accurate results. With the present invention, data is collected from an automotive vehicle while a starter motor of the vehicle is engaged to start an engine of the vehicle. This additional data is used to provide a battery test result. The battery test result can be based solely upon the data collected during the starting sequence or may also include additional data such as additional battery test data, batter charging data, or battery discharging data. The data collected during starting of the vehicle provides a starting voltage profile, which includes voltage information along with time information. This starter voltage profile is then correlated with battery condition. In a more specific configuration, first test circuitry is used to couple to a storage battery of the vehicle, apply a forcing function to the storage battery of the vehicle and measure a response of the storage battery to the applied

forcing function. This is used to provide a battery test output related to a condition of the battery. A starter voltage measurement circuit is electrically coupled to the starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times during operation of the starter motor. Second test circuitry is then configured to receive the battery test output and the starter voltage profile information. The second test circuitry provides an enhanced battery test output related to the condition of the battery which has improved accuracy over the battery test output provided by the first test circuitry.

(15) FIG. **1** is a simplified block diagram showing a battery maintenance system **100** coupled to an automotive vehicle **8**. The automotive vehicle **8** is illustrated as a battery **10**, a starter motor **14**, an engine **16** and a starter relay switch **18**. The vehicle **8** also includes an internal data bus illustrated as an OBDII data bus **20**. The battery maintenance system **100** also includes an OBDII connector **12**. As discussed more herein, battery maintenance system **100** performs electrical measurements on battery **10** using an electrical connection to the battery **10**. To collect starter profile information, the starter relay **18** is closed, which provides an electrical connection to the starter motor **14**. The starter motor **14** is caused to rotate thereby rotating the engine **16** allowing the engine **16** to start. During the starting sequence, data is collected by battery maintenance system **100** using the connection to battery **10**. The profile information includes a plurality of measurements taken over a time period. This time period can include time both before the starter relay switch **18** is closed and after the starter relay switch **18** is opened. Example data measurements include voltage measurements. Another example data measurement is a current measurement, for example, obtained using an amp clamp (not shown in FIG. **1**).

(16) FIG. **2** is a simplified block diagram of battery maintenance system **100** including measurement circuitry **50** connected to storage battery **10**. Measurement circuitry **50** provides outputs to first test circuitry **52** and starter voltage measurement circuitry **54**. As discussed herein, the first test circuitry **52** can perform a battery test on the battery **10** using measurement circuitry **50** by applying a forcing function to the battery **10** and observing a resultant dynamic electrical parameter of the battery **50**. Starter voltage measurement circuitry also couples to measurement circuitry **50** and measures a voltage across the battery **10** while the starter motor **14** shown in FIG. **1** is operated. In one configuration, the device **100** determines that the starter motor is being operated by observing a voltage drop in the measured voltage across the battery **10**. In another example configuration, starting information is collected using the data bus **20** of the vehicle. Further, an operator can be prompted, for example using display **220** illustrated in FIG. **6**, to engage the starter motor. The collected profile data can comprise, for example, a series of data points collected over a period of time at variable or fixed time intervals. Second test circuitry **56** is configured to receive a battery test result from first test circuitry **52** along with the starter profile information provided by the starter voltage measurement circuitry **54**. The second test circuitry provides an enhanced battery test output based upon the battery test result provided by the first test circuitry along with the starter voltage profile information provided by starter voltage measurement circuitry **54**. The second test circuitry **56** couples to a memory **60** which contains data which relates starter voltage profile information to a condition of battery **10**. This data correlates voltages along with profile information such as rate of change of measured voltage, minimum and maximum voltage levels, the shape of the profile, etc., to the condition of battery **10**. The second test circuitry can use this to verify the battery test determination provided by first test circuitry **52** or can use this information to improve the accuracy of the battery test information provided by first test circuitry **52**. In another example configuration, if the battery test result provided by first test circuitry **52** differs significantly from the battery condition determine obtained using the starter voltage profile information, second test circuitry can provide a battery test output based solely on the starter voltage profile information.

(17) FIG. **3** is a graph of voltage versus time and is an illustration of one example starter voltage

profile. FIG. **3** shows a series of dots which represent individual samples of voltage at particular times. In this configuration, the time between samples is evenly spaced. However, the data points need not be linearly spaced in time and can vary as desired. Additional data points can be used when the profile is changing rapidly to provide for greater accuracy. The voltage profile provides a number of different types of data. As shown, the profile provides voltages both before the starter motor engages at time T**1** as well as information after power is removed from the starter motor **14** by relay **18** at time T**2**. This allows information to be collected related to the rate at which the voltage drops when the starter motor is engaged illustrated as a slope S**1** along with information related to the rate of voltage recovery illustrated as slopes S**2** and S**3**. Voltage minimums and/or maximums can also be collected. Further, operation of the starter motor **14** introduces noise on the voltage measurements which can be seen during time period T**3**.

(18) FIG. **4** shows an example of datasets stored in array **63** which can be kept in memory **60**. The datasets include a series of starter motor voltage profile measurements indicated as profile **1**, profile **2**, profile **3**, . . . profile N. These profiles are a series of data points such as those discuss in connection with FIG. **3**. If the data points are collected at fixed or known intervals, time information does not need to be stored. Also stored in array **63** is a dataset of battery condition information. This is indicated as battery condition **1**, battery condition **2**, battery condition **3**, . . . battery condition N. The battery condition information is preferably obtained from the same battery from which the starter voltage profile information was obtained. The battery condition information can be obtained using any battery testing technique and can comprise, for example, battery state of charge, battery state of health, a pass/fail determination, or other battery condition. This can be determined, for example, using a measurement of a dynamic parameter in response to an applied forcing function, a load test, a charge acceptance test, a chemical test, a test of a physical property such as specific gravity, or other testing techniques. In one specific configuration, measurement circuitry **50** shown in FIG. **2** is used to apply a load test to battery **10** in which a load is applied across the battery and battery voltage and current flow is monitored as the battery is discharged. This can be used to make an accurate assessment of the amount of charge stored in the battery **10** and also used to determine battery health information. In a similar test, measurement circuitry **50** is used to apply a charge to the battery **10** and charge acceptance is monitored in order to determine battery state of health and battery condition. The starter voltage profile information for the associated battery is also stored in the memory. The array **63** can include other parameters obtained during battery testing such as battery voltage, current draws, temperature, battery type, battery rating, etc. Thus, in one example configuration, a starter voltage profile is obtained as discussed above and compared with the various profiles stored in array **63**. To determine the enhanced battery test output, a starter voltage profile is collected for a battery under test and a stored profile is selected which most closely matches the measured profile. The battery condition of the selected profile is identified and used to provide an enhanced battery test output indicative of the condition of the battery **10**. The particular matching technique can be selected as desired and can be a technique which matches the voltages at various time sequences and identifies the profile which most closely matches. Other techniques include matching slopes or rates of change such as S**1**, S**2** and S**3** illustrated in FIG. **3**. The amount of noise during the time period T**3** and voltage minimums or maximums can also be used in the matching period.

(19) The enhanced battery test output can be determined using any number of techniques, including machine learning. One example technique is a series of steps used to provide the output. For example, if the first battery test provides a battery dynamic conductance which indicates a good battery, but the starter voltage profile shows an unusually large voltage drop, a determination can be made that the battery is actually bad. The data set used to make these determinations can also include battery voltage, battery rating, temperature, current measurements, etc.

(20) FIG. **5** is an exploded view of a battery maintenance system **100** in accordance with one example embodiment. Battery maintenance system **100** includes an electronic battery tester **102**

and a base station **104**. Base station **104** includes a base **106** and a cover or lid **108**. In the configuration shown in FIG. **5**, base station **104** is configured for portable operation, however, a fixed or less mobile base station configuration may also be employed.

(21) The base station **104** includes a number of receiving areas **110**A-D for receiving various components (or accessories) of the battery maintenance system **100**. For example, battery tester **102** is received in receiving area **110**A. FIG. **5** also illustrates an amp clamp (current sensor) **120** which is received in receiving area **110**C, a OBDII communicator **122** which is received in receiving area **110**B and Kelvin connectors **124** which are received in receiving area **110**D.

(22) Any number of battery maintenance tools or accessories may be contained in receptacles of the base station **104** and the invention is not limited to those specifically discussed herein. Additionally, the Kelvin connectors **124** are illustrated as being connected to a plug connector **111**A. This plug connector may be used for coupling the cabling to the battery tester **102**. Additionally, the plug **111**A may be plugged into a socket **111**B carried in the base station **104**. The socket **111**B may be used in a configuration in which a battery carried within the base station **104** is used for jump starting the vehicle. In another example configuration, battery testing circuitry, or other testing circuitry is carried in base station **104** and electrically coupled to Kelvin connectors **124** through plug **111**A and socket **111**B.

(23) FIG. **6** is a simplified block diagram showing components and circuitry of the electronic battery tester **102**. Battery tester **102** includes a microprocessor **200** coupled to battery test circuitry **202**. Battery test circuitry **202** may operate in accordance with any battery testing procedure and one example procedure is discussed below in more detail. Battery test circuitry **202** is shown as coupled to Kelvin connector circuitry **204** and amp clamp circuitry **206**. Microprocessor also couples to a display **220** and user input/output **222**. An additional input/output circuitry **224** is illustrated along with wireless input/output circuitry **226**. Microprocessor **200** operates in accordance with instructions stored in memory **230**. A power supply **232** is illustrated and coupled to an optional battery **234**. Power supply **232** may obtain power through the connection to a battery under test, may obtain power through internal battery **234**, may obtain power through the base station **104**, or from some other source. In one configuration, battery **234** is charged when the battery tester **102** is coupled to a battery under test or when the battery tester **102** is coupled to base station **104**.

(24) In the configuration illustrated in FIG. **6**, the various components of the battery maintenance device **100** shown in FIG. **2** are implemented using a number of different blocks in the Figure. For example, measurement circuitry **50** can be implemented in block **202**. This can include, for example, a forcing function, a voltage measurement circuit, and/or a current measurement circuitry. The first test circuitry **52**, starter voltage measurement circuitry **54** and second test circuitry **56** can be implemented in microprocessor **200**. The memory **60** of FIG. **2** can be a wholly or partially implement in memory **230** of FIG. **6**.

(25) During operation, microprocessor **200** performs a test on a storage battery using connector circuitry **204** and optional amp clamp circuitry **206**. The amp clamp circuitry **206** may also be used to test other electrical components of an automotive vehicle such as, for example, a starter motor. The connection to the amp clamp **120** shown in FIG. **5** through amp clamp circuitry **206** may be a wired connection, or, for example, may be a wireless connection through wireless I/O **226**. Wireless I/O circuitry **226** may also be used to communicate with the OBDII communicator **122** and/or base station **104**. Base station **104** may also be used to relay communications to another location, such as a centralized location.

(26) The microprocessor **200** provides information to an operator using, for example, display **220** and may receive commands or other user input through user I/O **222**. I/O **224** may be used for communicating with other components or devices. For example, a remote printer may be accessed using circuitry **224**. The microprocessor can communicate with the OBDII databus of the vehicle using the OBDII communicator **122**. For example, this information can be used to determine

information about the vehicle under test, information about usage of the vehicle under test, information about the storage battery of the vehicle or other information related to the vehicle. Further, the communicator **122** may be used to provide data signals onto the OBDII databus of the vehicle. This may also be used to store information or other parameters in the vehicle, or control operation of components of the vehicle.

(27) FIG. **6** also illustrates tracking circuitry **240** which is used by circuitry in base station **104** to identify a location of the battery tester **102**. For example, the tracking circuitry may include addressing information whereby base station **104** may identify a unique battery tester **102** when it is placed into the receiving area **110**A of the base **106** shown in FIG. **5**. Note that the receiving area **110**A illustrated in FIG. **5** may also include an electrical connection for coupling to power supply **232** of the battery tester **102**.

(28) FIG. **7** is a simplified block diagram of amp clamp/current sensor **120**. Sensor **120** includes a current probe **300** coupled to measurement circuitry **302**. Probe **300** may operate in accordance with any appropriate technique for a particular use. Such techniques include inductive coupling, the use of a Hall Effect sensor, or some other technique including a shunt. Measurement circuitry provides an output to wireless I/O circuitry **304** related to the measured current. This information is transmitted wirelessly to the battery tester **102** shown in FIG. **6**. The current sensor **120** includes a power supply circuit **310** for providing power to the device. An internal battery **312** may be used for storing power. The battery **312** may be charged, for example, through a connection through power supply **310** to the receiving area **110**C of base station **104**. Tracking circuitry **326** is also provided.

(29) FIG. **7** also illustrates an optional optical sensor **320** carried by current sensor **120**. Optical sensor **320** may be used to receive optical information such as, for example, information provided by a barcode. The optical sensor **320** can be used to read information from the vehicle, for example, a VIN identification number of the vehicle, as well as information related to various components of the vehicle including serial numbers carried on storage batteries or other components of the vehicle. In another example configuration, optical sensor **320** comprises an infrared sensor for use in sensing temperature of various components of the vehicle or other components. For example, battery temperature can be used as part of a battery test.

(30) In another example configuration, the system **100** can be used for providing a jumpstart to a battery of a vehicle. In one such example configuration, the internal battery **234** of tester **102** is coupled to Kelvin connector circuitry **204** to apply a voltage to the battery for starting the vehicle using Kelvin connectors **124**. In such a configuration, the battery **234** should be able to deliver sufficient current at a high enough voltage to activate the starter motor of the vehicle. For example, a rechargeable lithium battery may be employed. In another related configuration, a “memory saver” function is provided by system **100**. This can be used if the battery of a vehicle is disconnected or removed from the vehicle in order to maintain the memory and other stored information within the vehicle. For example, the vehicle may be powered using battery **234** through the Kelvin connectors **124**. Other connection mechanisms may also be employed such as, for example, a connection to the OBDII databus, a connection through a “cigarette lighter” of the vehicle, etc.

(31) The tracking function discussed herein may also be used as a component of the testing function. For example, in order to ensure that all accessories are returned to their proper location, the system **100** can be configured to only provide a test result once all of the accessories are returned to their proper location within the base station **104**. Batteries or storage systems within the various components can store power during the testing process in which power is received from the battery or the vehicle under test. Other charging techniques may also be employed such as, for example, through an electrical connection to the base station **104**. The amp clamp **120** may also include additional electronic circuitry and input/output circuitry to perform tests of its own. For example, such circuitry can be used to provide an operator with information related to the amount

of current being sensed during a particular operation of the vehicle. Other diagnostic functionality may also be implemented.

(32) FIG. **8** is a simplified block diagram of the OBDII communicator **122** shown in FIG. **5**. Communicator **122** includes an OBDII interface **400** for connection to an OBDII data port of an automotive vehicle. This allows a two-way communication with the databus of the vehicle. Although an OBDII interface is illustrated, interface **400** may communicate with any type of vehicle databus or the like. Communicator **122** includes a power supply **410** for use in providing power to the device. An internal battery **412** is used for powering the communicator **122**. The battery of **412** may be charged, for example, when the communicator **122** is placed in the receiving area **110**B shown in FIG. **5**. Wireless communication circuitry **420** is provided for use in wirelessly communicating with the battery tester **102**. The wireless communication circuitry **420** may also be used to communicate with base station **104**. Using this communication circuitry **420**, the devices can communicate with the onboard databus of a vehicle using the OBDII interface **400**. Tracking circuitry **430** is also provided and may include a unique address at which identifies the communicator **122**. Further, the tracking circuitry **430** may be used by base station **104** to identify positioning of the communicator **122** within the receiving area **110**B.

(33) FIG. **9** is a simplified diagram of Kelvin connectors **124** used to connect to battery **10**. Kelvin connectors **124** include a pair of Kelvin connections **500**, **502** each containing two electrical connections. Kelvin connections **500**, **502** may be configured in alligator clamps **504**, **506**, respectively, or the like. Cabling **510**, **512** is used to provide a physical electrical connection to the battery tester **102** shown in FIG. **5**. Tracking circuitry **520** may include a unique address for use in identifying the Kelvin connector **124**. This may also be used for determining placement of the Kelvin connector **124** into the receiving area **110**D of the base station **104**.

(34) FIG. **10** is a simplified block diagram of base station **104**. Base station **104** includes a microprocessor **600** optionally connected to receptacles **110**A-D. Using this optional connection, microprocessor **600** may use a physical connection to the tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124** for communication. This may be for downloading parameters, programming the device, or for other usage. Microprocessor **600** also couples to a communication hub **604**. Communication hub **604** provides both wireless and wired communication. For example, information can be communicated to a remote location including a data “cloud”, using wireless or wired communication techniques including WiFi, cellular data transmission, hard wired Ethernet, Bluetooth®, etc. Communication hub **604** may also be used for wirelessly communicating with the various components of the system **100** including the battery tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124**. Optional user input/output may also be provided for the communication hub, for example, for displaying information or receiving a user input. Communication hub **604** may be used for communicating with a local device such as a printer as well as a portable user interface, for example, provided by a tablet computer, cellular phone, or other device including an application specific device. Microprocessor **600** is coupled to a memory **608** which is used to store programming instructions as well as store calibration parameters, etc. Further, test measurements or the like may be stored into the memory **608**. Base station **104** includes a power supply **610** used for powering components of the base station **104**. Power supply **610** may also be used for recharging batteries carried by the battery tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124**. An optional battery **612** is provided for powering the base station **104** when an external power source is not available.

(35) Base station **104** includes tracking circuitry **620**. Tracking circuitry **620** is used to communicate with the tracking circuits carried within the various accessories of the system **100**. In a specific example, the tracking circuitry **620** communicates with the tracking circuit **240** of battery tester **102**, the tracking circuit **430** of OBDII **122**, the tracking circuit **520** of Kelvin connectors **124** for determining when they are placed within their receiving areas **110**A-**110**D of base station **104**.

Further, the various components may wirelessly communicate with tester **102** and/or base station **104**.
(36) FIG. **11** is a more detailed block diagram of battery tester **102** which includes a forcing function **740** and an amplifier **742** coupled to connectors **500**. In the illustration of FIG. **7**, connectors **500** are shown as Kelvin connections. The forcing function **740** can be any type of signal which has a time varying component including a transient signal. The forcing function can be through application of a load or by applying an active signal to a battery. A response signal is sensed by amplifier **742** and provided to analog to digital converter **744** which couples to microprocessor **200**. Microprocessor **200** operates in accordance with instructions stored in memory **230**. Microprocessor **200** can store data into memory **230**.
(37) Of course, the illustration of FIG. **11** is simply one simplified embodiment and other embodiments are in accordance with the invention. In the illustrated embodiment microprocessor **200** is configured to measure a dynamic parameter based upon the forcing function **740**. This dynamic parameter can be correlated with battery condition as set forth in the above-mentioned Champlin and Midtronics, Inc. patents. However, other types of battery tests circuitry can be used in the present invention and certain aspects of the invention should not be limited to the specific embodiment illustrated herein. FIG. **11** also illustrates an input/output circuitry **222** which can be any other type of input and/or output coupled to microprocessor **46**. For example, this can be used to couple to external devices or to facilitate user input and/or output. Although a microprocessor **200** is shown, other types of computational or other circuitry can be used to collect and place data into memory **230**. Further, in one configuration, the forcing function **740** can be configured as a large electrical load for performing a load test. In another example configuration, the forcing function **740** provides a battery charging function is which charge is applied to the storage battery and monitored to determine battery condition.
(38) Further, using the system set forth herein, a battery maintenance system which includes machine learning is provided. FIG. **12** is a simplified block diagram of a machine learning model training **700** and a machine learning model prediction **702** in accordance with a further embodiment of the invention. In such a configuration, the test equipment **100** set forth herein is configured to gather data such starter voltage profile information and battery condition information as shown in FIG. **4**. The data then is analyzed and acted upon using machine learning techniques performed either locally, remotely, or in a hybrid fashion. As set forth in FIG. **12**, the machine learning training mode includes gathering test data followed by exploratory data analysis. The collected data is cleaned if necessary to remove undesired data points. This cleaning function includes removing outlier data, data with excessive noise, etc. A feature engineer step is provided followed by a train and test machine learning model. The feature engineering step can be used to discard bad data. For example, an unusually cold temperature measurement obtained in a warm climate can be identified and discarded. Any appropriate feature engineering technique can be used. The machine learning can be through known neural network or other machine learning techniques. The model is then evaluated but collecting additional starter voltage profile and battery condition information and comparing the results from the model with actual measured battery conditions. Parameters are fine-tuned as desired. A model can then be deployed in service either locally at a test location, remotely at a cloud-based location for example, or in a hybrid combination of such locations.
(39) Similarly, the system includes a machine learning model prediction phase **702** once the model is sufficiently trained and put into service. In this phase, data is gathered and cleaned along with processed through a feature engineer. The data is then used to predict a battery test result or other test result including an alternator test result. This prediction is then output as desired, for example this prediction can be output locally and/or transmitted to a remote location. The steps in accordance with the machine learning model training mode are set forth below in more detail: Connect tester clamps to battery and perform a battery test and starter test on a vehicle. Send the battery test and starter test measurement and result data to a test database. Record corresponding

DCA (Dynamic Charge Acceptance) test if battery test result is charge and retest and technician charges the battery on a charger. Clean the data for bad data, missing data and outliers. Perform stratified sampling to ensure a good representation of all the decisions in the dataset are present. Simplify from multiple decision types to a binary decision type (Good battery, Bad battery). Transform information into a format that can be interpreted by the machine learning model: Convert starter data from a single cell colon separated data to an array format with multiple readings per second. Feature engineer data to obtain information about battery health, for example, using the array format above to calculate the average voltage of the starter test. Transform additional data columns such as temperature to ensure they are in the consistent measurement unit. Divide this simplified and transformed data into two sets of training data and test data. Supply this training data to multiple Machine Learning algorithms for building the model. Apply the ML model to the test data to measure the accuracy and cross validation score. Evaluate the models for accuracy, sensitivity, specificity, cross validation and log loss. Fine tune model parameters. Deploy the model to production for real-time battery decision prediction. Retrain and redeploy the model with new data if the data distribution deviates significantly from the initial training set.

(40) Similarly, once the machine learning model is deployed into service, a prediction model is implemented as follows: Connect tester clamps to battery and perform battery and starter test. Clean the measurement data for bad data, missing data and outliers. e.g., voltages above “x” volts or Temperatures above “y” Fahrenheit. Transform the data in a format that can be interpreted by the machine learning model. Convert starter data from a single cell colon separated data to an array format with multiple readings per second. Feature engineer the data e.g. using the array format above to calculate the average voltage of the starter test. Additional data columns such as temperature are transformed to ensure they are in the same measurement unit. Supply transformed data to the machine learning model in production. Return the predicted battery result to the tester/charger and data cloud.

(41) The particular machine learning can be implemented using standard computer programming techniques which are known in the art such as neural networking techniques. The techniques can be used to test automotive vehicle batteries (including electric and hybrid vehicles), backup power supply batteries, etc., as well as components of automotive vehicles such as starter motors.

(42) In one specific configuration, voltage is measured at a rate of 1000 samples per second. Any number of data points can be collected. In one embodiment, 513 data points are collected. If a training dataset is imbalanced, for example, having disproportionately high number of “good” battery tests compared to “bad” battery tests, the data can be balanced using known techniques. For example, stratified sampling can be used, SMOTE (Synthetic Minority Over-sampling Technique) can be used, or others. Further, outlying data in standard deviations, mean and median voltage value, or other parameters can be discarded from the training model. Once a model is trained for example, using the XGBoost method, the model parameters such as Tree depth, minimum child weight, learning rate, etc., can be fine tuned.

(43) Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. The devices described herein, in some embodiments, may be capable of wireless communication. The particular wireless communication technique may be implemented as desired. Examples include Bluetooth® communication techniques, near field communication techniques, WiFi communication techniques, cellular communication techniques or others. The test performed by the battery tester **102** may be a function of information input by a user, or information received from other sources, such as the VIN of the vehicle. The VIN information may be obtained using a barcode scanner or through the connection to the OBDII databus. Based upon a particular vehicle, the battery test can be adjusted accordingly. The amp clamp **120** may be used in conjunction with the battery test, or may be used for performing other tests on the vehicle. Such tests include measuring starter current, phantom

current draws, charging current, etc. The testing and measurements circuits and components, along with memory and logic functionality, discussed herein can be implements in shared components and need not be discrete components. For example, the same voltage sensor used to measure a dynamic parameter can be used to collect starter voltage profile information. The memories and logic functionalities illustrated and discussed herein can be implemented locally, remotely, or a combination of local and remote implementations. Although the starter voltage profile is described herein as voltage data, current data may also be used as the two parameters are related. For example, current flowing from the battery while the starter motor is engaged is related to a voltage drop across a series resistance, a voltage output from an amp clamp, etc. In one aspect, the machine learning model eliminates the need to charge the battery and retest the battery, thus reducing the required to complete a battery test.

Claims

1. An electronic battery tester for testing a storage battery in an automotive vehicle, comprising: first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the applied forcing function; starter voltage measurement circuitry configured to electrically couple to a starter motor of the automotive vehicle and collect starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor; and second test circuitry configured to receive the battery test output from the first test circuitry and the starter voltage profile information and provide an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.
2. The electronic battery tester of claim 1 wherein the starter voltage measurements comprise a voltage across a storage battery of the automotive vehicle.
3. The electronic battery tester of claim 1 including a connection to a databus of the vehicle.
4. The electronic battery tester of claim 3 wherein the starter voltage measurements are obtained through the databus of the vehicle.
5. The electronic battery tester of claim 1 including an output to prompt an operator to engage the starter motor of the vehicle.
6. The electronic battery tester of claim 1 wherein the voltage measurements are obtained at fixed time intervals.
7. The electronic battery tester of claim 1 wherein the voltage measurements are obtained at variable time intervals.
8. The electronic battery tester of claim 1 including a memory configured to store the starter voltage measurements.
9. The electronic battery tester of claim 1 wherein the starter voltage measurements are used to determine a condition of the storage battery.
10. The electronic battery tester of claim 9 wherein the condition of the storage battery determines using the first test circuitry and the condition of the storage battery using the starter voltage measurement circuitry are compared for verification.
11. The electronic battery tester of claim 1 wherein the starter voltage measurements include a measurement obtained before the starter motor is engaged and a measurement obtained while the starter motor is engaged.
12. The electronic battery tester of claim 1 wherein the starter voltage profile information is compared with stored starter voltage profile information to determine a condition of the storage battery.
13. The electronic battery tester of claim 1 including a memory configured to store a plurality of

starter voltage profile measurements.

14. The electronic battery tester of claim 13 wherein the plurality of stored starter voltage profile measurements are associated with a condition of the storage battery.

15. The electronic battery tester of claim 1 wherein the condition of the battery is further determined based upon a temperature.

16. The electronic battery tester of claim 1 wherein the condition of the battery is determined using the starter voltage profile information and machine learning implanted by the second test circuitry.

17. The electronic battery tester of claim 1 wherein the enhanced battery test output is a function of a slope in the starter voltage profile information.

18. The electronic battery tester of claim 1 wherein the second test circuitry monitors noise present in the starter voltage profile information.

19. The electronic battery tester of claim 1 wherein if the battery test output from the first test circuitry indicates a good condition of the storage battery and the starter voltage profile information shows an unusually large voltage drop, the enhanced battery test output comprises a bad battery determination.

20. The electronic battery tester of claim 1 wherein the enhanced battery test output is further a function of current measurements.

21. The electronic battery tester of claim 1 wherein the second test circuitry discards starter voltage measurements which are determined to be bad data.

22. The electronic battery tester of claim 1 including communication circuitry to communicate the starter voltage profile information to a remote location for training of machine learning.